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GROUNDWATER STUDY AT NANTICOKE ASH LAGOON PART 2: CHEMICAL ANALYSIS OF LOCAL GROUNDWATERS

Report No 90-214-K

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ABSTRACT

A hydrogeological investigation was initiated in the fall of 1986 within and around the existing Nanticoke TGS fly ash disposal area. The objective of this study was to determine the environmental impact of fly ash disposal on the groundwater regime beneath the ash lagoon. The results of the study could be applied to the design and siting of future FGD waste disposal operations. The field program consisted of installing 6 "piezometer nests" both within and outside the fly ash disposal area. These piezometers were used for the collection of water samples as well as hydraulic head monitoring and hydraulic conductivity testing. The chemistry of the overburden groundwater below the ash lagoon was also determined by extraction of pore water from undisturbed soil cores. Selected soil samples from near the fly ash/clay interface were analyzed for total concentrations of arsenic and selenium. The results of the three types of sampling and testing are summarized and discussed. Pore water extraction from undisturbed soil cores has proven to be the most reliable method of obtaining geochemical data from below the ash lagoon.

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GROUNDWATER STUDY AT NANTICOKE ASH LAGOON
PART 2: CHEMICAL ANALYSIS OF GROUNDWATERS

1.0 INTRODUCTION

To assess the impact of the Nanticoke TGS fly ash disposal area on local groundwater resources, a hydrogeological investigation was initiated in the fall of 1986. The ash lagoon began operations in the early 1970s, therefore, any potential environmental impact should have already developed. This long-term investigation, conducted by the Soil Sciences Section of the Civil Research Department, would help clarify the extent of movement of ash leachate constituents from the disposal lagoon into the underlying clay overburden and bedrock. Assuming that the characteristics of fly ash leachate and FGD leachate are reasonably similar, the results of this study could assist in impact assessments of future FGD disposal systems.

The field program consisted of installing several nests of piezometers, both underneath and around the fly ash disposal lagoon, for the purpose of obtaining water samples for chemical analysis. Soil sampling from underneath the ash lagoon was also undertaken to allow for chemical analysis of pore water as well as trace element analysis of the soil itself.

The results of all hydraulic testing and of hydraulic head monitoring in the piezometer nests are provided elsewhere/1/. This report provides the chemical analysis results for groundwaters sampled from piezometers and for pore waters squeezed from soil samples. The analyses of soils for selected trace elements are also reported.

1.1 Operating History of the Ash Lagoon

The Nanticoke Thermal Generating Station has a capacity of 4100 megawatts (MW) from its eight units and is one of the largest coal-fired stations in the world.

Construction began at the site in 1968 and all eight units were completed by late 1978. Simultaneous operation of all eight units began in 1981. A blend of US coal and low sulphur Canadian coal has been burned at the station since 1979 as one of the measures for controlling sulphur dioxide emissions. At full load, the plant will burn up to 1480 megagrams of coal per hour. Actual coal consumption and fly ash production varies with power demand, maintenance schedules at the plant and availability of electrical power from other sources within the Ontario Hydro grid. The average annual ash production at Nanticoke is approximately 600 Gg.

To handle the large quantities of fly ash and bottom ash produced during the coal burning process, a large above-ground lagoon was constructed with a surface area of 76 ha and a height of 12 m. The original ground surface was graded to an elevation of 184.75 m ASL and a clay dyke was constructed up to an elevation of 197 m ASL to form the lagoon. Levelling of the original ground surface required removal of 1 to 3 m of clay overburden throughout most of the ash disposal area. A natural drainage creek, flowing southeast across the site, had to be filled in since its depth ranged from 1.2 m to 4.9 m below the design bottom of the lagoon/2/.

The ash handling operation, which began in 1972, consisted entirely of a wet system. The fly ash and bottom ash were sluiced from the station up to the lagoon and allowed to settle. The water within the reservoir was recirculated back to the station for ash transport. The lagoon also received aqueous waste from coal pile runoff, air preheater washes, demineralization plant, boiler cleaning and the sewage lagoon/3/. As the ash delta continued to build up over the years, the water level in the lagoon also began to rise such that in 1981, the exposed ash delta surface was approximately at elevation 195 m and the lagoon level was at elevation 194 m/4/. This translates to a hydraulic pressure of approximately 9 m of water acting at the top of the clay overburden.

In 1979, the Nanticoke station began blending low sulphur, western Canadian coal with Eastern US coal. The procedure had a detrimental effect on the recirculatory ash sluice system and the ash lagoon. The higher calcium oxide content of the western Canadian coal increased the lagoon pH and also caused scaling problems within the sluicing system. The higher ash content of the Canadian coal

contributed to reducing the expected operating life of the lagoon. Because of these and other factors, in 1981 the ash handling system was converted to a once-through wet ash transport system.

The new system, which is still in operation, involves sluicing the ash into several sedimentation cells. These cells were constructed by excavating into the existing ash delta and by constructing retaining dykes with compacted ash. Interconnection between the various cells is achieved through a series of culverts. The cells are periodically dredged and the accumulated ash stockpiled behind a berm to reduce wind erosion. The transport water is clarified in a series of sedimentation cells and then further clarified in the primary lagoon before being circulated back to the station and discharged to the condenser cooling water outfall (Figure 1). The water level in the primary lagoon, which now only covers approximately one third of the original surface area, tends to fluctuate between elevations 189 m and 191 m, depending on coal consumption rates. The design height of the ash stockpile is at elevation 218 m or 15 m above the crest of the original clay dyke.

2.0 SITE GEOLOGY

Nanticoke TGS is located in the physiographic region of southwestern Ontario known as the Haldimand Clay Plain. The overburden in the area consists mostly of a faintly layered, over-consolidated glacial-lacustrine clay which was deposited in glacial Lake Warren. The lacustrine clay is extensively fractured near the surface and the fracture frequency diminishes with depth.

Trench fracture mapping results reported by Golder Associates/5/ indicate that the majority of fractures are vertical to sub-vertical and are identifiable by a distinct blue-grey colouration along the fracture planes, as well as the presence of extensive root systems. Abundant horizontal to sub-horizontal partings were noted in association with thin silt l yers suggesting the presence of varves. A third set of shallow dipping fractures (approximately 45°) was also identified which had occasional slickenslided surfaces indicating previous movement in the direction of the dip. Fracture surfaces were visible at the base of the mapping trenches, which indicates that fracturing extends from the surface to a depth of at least 5.2 m below ground surface.

The detailed stratigraphy of the site consists of 8 to 11 m of lacustrine silty clay overlying 0 to 2 m of sandy silt till. The till is underlain by bedrock described as brownish-grey, fine-grained cherty limestone and known as the Dundee formation of Devonian age. The bedrock surface is occasionally highly fractured with fracturing decreasing with depth/5/.

In the vicinity of the Nanticoke ash lagoon, the bedrock surface elevation ranges from 175 to 177.5 m ASL. Since the design bottom of the lagoon is at an approximate elevation of 185 m, this implies that overburden thickness underneath the lagoon varies from 7.5 to 10 m. With up to 3 m of overburden removed to obtain the design elevation of the lagoon, a large portion of the near-surface fractured zone was also removed and reworking of the clay surface may have sealed any remaining fractures. No specifications have been found for the infilling of the creek which crosses the site.

3.0 WATER SAMPLING AND TESTING METHODOLOGY

3.1 Piezometer Installation

All standpipe-type piezometers were constructed of 3.8 cm inside diameter PVC pipe, slotted along a 30 to 120 cm length at one end and wrapped with geotextile. Most of the boreholes were drilled using 6 inch (15.2 cm) diameter hollow-stem augers and centrebit. Continuous or discrete soil sampling, using 4.7 cm diameter Shelby tubes, was performed during the installation of most piezometers. Piezometers were installed just below the till/bedrock contact by drilling a 1.5 m long core of the fractured limestone. Coarse filter material consisted of a mixture of pea gravel and/or sand and a 30 to 60 cm long bentonite plug was placed to seal the piezometer intakes. Piezometers installed outside of the ash lagoon were backfilled with native clay, while those inside the lagoon were backfilled to the near-surface with a cement/bentonite mix. Piezometer intake lengths ranged from 40 cm to 200 cm depending on their location.

Piezometers were installed at six different locations in and around the fly ash lagoon, as shown in Figure 1. At each location, several piezometers were placed at different depths forming "nests" of monitoring points. The elevations of all monitoring points are given in Table I.

Nests #1 and #6 are located outside the southeast and northeast corners of the lagoon respectively. Nests #2 through #5 are located within the ash lagoon itself. At locations #2 and #3, two piezometers were placed in the ash, three in the overburden and one in the bedrock. At locations #4 and #5, two bundle piezometers were placed in the ash, five standpipe-type piezometers in the overburden and one in bedrock. The bundle piezometers consist of 0.9 cm and 1.3 cm diameter polyethylene tubing cut to specific lengths and bundled together. Each bundle consists of six tubes and each tube has a filtered intake up to 15 cm in length placed at one end. Monitoring points in the fly ash extend from 6 ft (1.8 m) to 28 ft (8.5 m) at 2 ft (0.6 m) intervals.

The six piezometer nests, shown in Figure 1, were installed at different times throughout the project. Nests #1 to #3 were installed in early-October of 1986. Nest #1 was used to provide background values of hydraulic heads and water quality. Nest #2 was installed to allow monitoring of hydrogeological parameters within the infilled drainage creek. Nest #3 was located in the area of the ash outlet pipes, to help determine the effects of long-term contact between the ash and overburden. Nests #4 and #6 were installed in April of 1987. Nest #4, similar to Nest #3, was used to provide hydraulic and geochemical data from the area of longest contact between ash and clay. Nest #6 was used to provide background data upgradient of the ash lagoon. Nest #5, installed in late August, 1987, was used to provide additional data from underneath the ash lagoon and its location was chosen for purely practical reasons.

3.2 Groundwater Sampling and Testing

The results of the chemical analyses of groundwater sampled from around and below the Nanticoke ash lagoon are provided in Tables II through V. Piezometer Nests #1, 2 and 3 were sampled on January 26 and June 17, 1987; Nest #4 was sampled on November 5, 1987; Nests #1 through #6 were sampled on July 27, 1988. Due to continuously expanding activities within the ash disposal area, piezometer Nests #2 and #3 have been backfilled and abandoned.

Prior to sampling for chemical analysis purposes, all piezometers were bailed down to approximately the top of each intake length. Formation water was allowed to recharge the piezometers over several weeks before groundwater sampling proceeded. Water was removed from the piezometers with either a teflon or stainless steel bailer which was thoroughly cleaned between each sampling with deionized water. All groundwater samples were immediately filtered through a cellulose nitrate, 0.45 micron, membrane filter. In general, three 250 mL samples of filtered groundwater were taken; two unacidified for the analyses of anionic species and alkalinity and one acidified with ultra pure HNO_3 for cationic species. All samples were labelled and stored in an ice-filled cooler for transport to the laboratory. Measurements of pH and conductivity were performed in the field on all sampling occasions. Field measurements of Eh and alkalinity were performed during the second sampling only. On other occasions, alkalinity measurements were obtained in the laboratory within 24 hours. The first set of major ion chemical analyses were performed by the Analytical Services Section of the Chemical Research Department. The remaining analyses were performed at the University of Waterloo.

Cation/anion balances were calculated for each sample listed in Tables II through V. This value, expressed as a percentage, is a reflection of the quality of the total analysis and is considered acceptable if within 10%. For the CAB values reported in Tables II to V, negative values represent an excess of anionic species, eg (Cl^-, $SO_4^=$, HCO_3, OH^-) and positive values represent an excess of cationic species, eg (Ca^{++}, Mg^{++}, Na^+, K^+).

3.3 Interstitial Water Sampling

To avoid the risks associated with conventional piezometer installations, such as fly ash contamination on augering equipment and/or failure of bentonite seals, in situ groundwater can also be obtained by mechanical squeezing of undisturbed soil cores/6/. The squeezing technique is a very useful method for obtaining water samples from exact locations and for diminishing the risk of contamination when sampling below a containment lagoon. Some of the disadvantages of the method when applied to fine-grained soils are that: 1) only small volumes of pore water are collected which limits the extent of chemical analysis and 2) during the time period required for storage and squeezing of the soil samples, chemical alterations such as precipitation and/or dissolution may affect the pore water chemistry.

As part of this hydrogeologic investigation, three soil core profiles were obtained from below the Nanticoke TGS ash lagoon using continuous tube sampling: one soil core profile was obtained in the vicinity of Nest #4 and two profiles were obtained, at different times, from the area of Nest #5. In the laboratory, the Shelby tube samples were extruded and then squeezed in a large Teflon squeezer. Because of the low permeability of the Nanticoke clays and because of pressure limitations of the squeezing apparatus, up to 24 hours was required to obtain approximately 30 mL of pore water in the sampling syringe. All samples were filtered through 0.45 μm filter paper and refrigerated until analyzed for major cations and anions.

3.4 Bulk Soil Analysis for Arsenic and Selenium

Bulk soil analyses for arsenic and selenium were performed on selected samples from underneath the ash lagoon, to help determine the extent of trace element adsorption and/or diffusion into the overburden. The soils selected for analysis were from Shelby tube samples obtained near the fly ash/clay contact and at depth during the installation of piezometer Nests #2 and #3. Tube samples were sectioned in 5 mm lengths and oven dried. Selected discs were submitted for analysis to the Analytical Services Section of the Chemical Research Department. Both atomic adsorption

spectroscopy and neutron activation analysis were used to determine bulk concentrations of arsenic and selenium.

4.0 PIEZOMETER WATER SAMPLES

The results of the groundwater analyses from around and below the Nanticoke TGS ash lagoon are provided in Tables II through V. The objective of these analyses was to determine if the presence of the ash lagoon had an impact on the chemistry of the underlying overburden and bedrock groundwaters. Three mechanisms of contaminant transport are possible at the Nanticoke site: 1) matrix diffusion in a very low groundwater velocity regime, 2) advection coupled with diffusion through the clay matrix under high groundwater velocity and 3) advection coupled with diffusion through open fractures in the clay overburden. Based on hydraulic conductivity, hydraulic gradient and intrinsic porosity values determined from piezometer Nests #2, 3, 4 and 5, groundwater velocities were estimated at 22, 115, 1.5 and 3.5 cm/a respectively/1/. The three order of magnitude difference in velocities is representative of the heterogeneous hydraulic conductivity conditions measured in the overburden across the lagoon site.

Assuming that groundwater velocities have remained constant throughout the lifetime of the ash lagoon, and that plug flow conditions exist within the overburden, it is possible that unattenuated ash leachate may have reached bedrock in selected areas. Unattenuated leachate migration in continuous, open fractures within the overburden may have also lead to significant transport distances.

In examining the results of the chemical analysis, one must be aware of: 1) the heterogeneity in transport conditions which exist within the overburden and 2) the integrity of piezometer installations beneath the containment lagoon.

4.1 Background Chemistry

Piezometer Nests #1 and 6 were installed to provide background values of hydraulic and geochemical conditions. In addition to these two nests, an extensive array of piezometers have been installed to the east and north of the Nanticoke TGS property by Golder Associates of Mississauga/7/. These installations were part of a hydrogeologic investigation of adjacent properties for the purpose of expanding the disposal area in the future. Chemical analysis of groundwater was conducted as part of the investigation and these results have also been used in this report to establish ranges of relevant ion concentrations. Average values for Ca, Mg, K, Na, Cl, HCO_3, SO_4, B, Sr and pH are provided in Table VI.

A distinction has been made between overburden and bedrock groundwaters. Mean values of Mg, Na and SO_4 concentrations are somewhat higher in the overburden than in the bedrock, however, variability in concentrations are also higher in the former than the latter as indicated by standard deviation values. Boron concentrations are slightly higher in bedrock groundwaters and arsenic was detected in two isolated cases/7/. Average sulphate concentrations for both overburden and bedrock groundwaters are 2578 and 1955 mg/L respectively. These values are 4 to 5 times higher than the Ministry of the Environment's Ontario Drinking Water Objective (ODWO) of 500 mg/L. Average sodium concentrations of 243 and 174 mg/L are substantially higher than the ODWO of 20 mg/L and the upper range of calcium concentrations (419 and 445 mg/L) also exceeds the ODWO of 250 mg/L. Because of its high hardness and total dissolved solids, the quality of both overburden and bedrock groundwaters may be classified as poor.

4.2 Nanticoke Fly Ash Leachate Chemistry

The chemistry of fly ash pore water at Nanticoke TGS has been determined in this study by sampling waters from standpipe and bundle piezometers installed in the ash disposal area. The piezometers in question are labelled 2-5, 2-6, 3-5, 3-6 and 4B-X in Tables II to V. The mean values of various elements in Nanticoke fly ash pore water are reported in Table VII for comparison purposes.

The major ion chemistry of Nanticoke fly ash pore water shows a large spatial variability as exemplified by the more diluted elemental concentrations from the bundle piezometers at Nest #4 compared to the standpipes of Nests #2 and 3. This phenomenon is probably due to the variability in bulk fly ash chemistry and to the many local flow systems within the disposal area. This second factor, referred to in a previous report on the physical hydrogeology of the site/1/, has probably contributed to variable amounts of ash leaching throughout the disposal area. However, the fly ash leachate chemistry shows less variability than the overburden or bedrock groundwater chemistries of Table VI.

The mean values of major ion concentrations (Ca^{++}, Mg^{++}, Na^{+}, $SO_4^{=}$) are generally less in fly ash pore water than in the background waters. Potassium concentrations are higher in fly ash pore water and pH's are distinctly alkaline. The elements which may be used as ash leachate indicators are

boron, arsenic and selenium, since they are present in higher concentrations than in the background waters.

Because of the leaching conditions which existed within the ash lagoon since it began operation in the early 1970s, it cannot be assumed that the present fly ash leachate chemistry reflects past conditions. Distilled water leach tests have been conducted on lagoon and precipitator ashes from Nanticoke TGS and the results have been recently summarized/8/. The concentration ranges for fly ash leachate indicators are as follows: 1) for boron, 1.4 to 6.0 mg/L; for arsenic, 0.007 to 0.3 mg/L; for selenium, <0.19 to 0.055 mg/L. The pH units range between 10.7 and 11.2. The upper range for arsenic and selenium are higher than those reported in Table VII.

4.3 Results of Piezometer Water Analyses

4.3.1 Nest #2

The piezometers of Nest #2 located within the overburden are 2-4, 2-3 and 2-2.

Piezometer 2-4, located immediately below the fly ash/clay interface, showed the highest concentration of arsenic of 0.029 ppm. The arsenic concentration dropped to 0.003 ppm during the second sampling and rose to 0.02 ppm on the third sampling. Boron concentrations steadily rose from 1.2 ppm to 6 ppm during the three sampling periods.

At piezometer 2-3, located approximately 1.5 m below 2-4, arsenic concentrations decreased from 0.002 ppm to below detection with each sampling. In contrast, boron concentrations steadily rose from 2.4 to 17.3 ppm during the same period as pH units decreased from 7.2 to 6.8.

At piezometer 2-2, approximately 3 m below 2-3, arsenic concentrations remained constant between 0.006 - 0.008 ppm. Boron concentrations remained at background levels while pH units dropped from 11.8 to 8.2 during sampling.

In the bedrock piezometer, 2-1, arsenic concentrations started at 0.064 ppm (higher than any pore water values), dropped to 0.003 ppm and rose again to 0.014 ppm at the third sampling. Boron concentrations rose steadily from 7.6 to 11.1 ppm while pH units varied from 7.09 to 7.48.

Selenium concentrations dropped quickly from 0.006 ppm to below detection (<0.003) for all piezometers and sampling periods.

The erratic arsenic and boron concentrations tend to suggest that some fly ash contamination occurred during installation of the piezometers and that numerous flushings would be required to ensure that water chemistries are representative of in-situ conditions.

4.3.2 Nest #3

Piezometers 3-4, 3-3 and 3-2 are located within the overburden.

At piezometer 3-4, located below the ash/clay interface, arsenic concentrations rose from 0.003 to 0.019 ppm. Boron concentrations rose from 0.19 to 2.54 ppm between the first and third samplings.

At piezometer 3-3, located 3.2 m below 3-4, arsenic concentrations were higher and also fluctuated from 0.105 to 0.027 and finally 0.113 ppm. These values are substantially higher than any recorded in the fly ash piezometers. Boron concentrations dropped from 3.8 to 1.8 ppm and then rose to 2.9 ppm during the third sampling. The pH dropped from 9.1 to 8.1 units during sampling.

At piezometer 3-2, located approximately 3 m below 3-3, arsenic concentrations dropped from 0.017 to 0.007 ppm and boron concentrations dropped from 2.1 to 0.7 ppm during sampling.

Selenium concentrations dropped to below detection (<0.002 ppm) after the first sampling of all piezometers. Bedrock piezometer 3-1 leaked shortly after the first sampling/1/. It was subsequently grouted and abandoned.

The arsenic concentrations measured at piezometer 3-3 are disturbingly high. However, the fact that they are not consistent, that concentrations at 3-4 are an order of magnitude less, and that concentrations measured in fly ash pore water are also much lower, tends to suggest that the high values are not associated with a contaminant front. The remaining ash indicator concentrations were more reasonable and tended to decrease with time. This implies that more purging of the piezometers would be required before in-situ conditions are reached.

4.3.3 Nest #4

Nest #4 was only sampled twice: November 5, 1987 and July 27, 1988. Five of the six piezometers at Nest #4 were installed in overburden commencing with 4-6 located just below the fly ash/clay interface.

At location 4-6, arsenic concentrations rose from 0.127 to 0.215 ppm and boron dropped from 3.3 to 2.7 ppm. At location 4-5, 2.3 m below 4-6, arsenic dropped from 0.047 to 0.014 ppm and boron dropped from 0.8 to 0.5 ppm.

At location 4-4, 1.0 m below 4-5, unusually high hydraulic heads were measured/1/. Unusually high arsenic concentrations dropped from a value of 0.240 to 0.086 ppm and boron remained relatively constant at 1.7 ppm. At location 4-3, 1.0 m below 4-4, arsenic concentrations remained at 0.020 ppm and boron remained at background levels.

No significant concentrations of arsenic, selenium or boron were detected at location 4-2 and 4-1. In addition, during the second sampling, selenium concentrations for all piezometers were below detection (<0.003 ppm).

Once again, the unusually high arsenic values and their spatial and temporal variations, do not lend themselves to interpretation. In addition, the results of the first sampling of Nest #4 are questionable because of the high cation/anion balances.

4.3.4 Nest #5

Piezometer Nest #5 was the last nest installed and consequently was only sampled once. Both arsenic and boron were detected in all piezometers at concentrations above background. Arsenic concentrations tended to decrease from 0.086 ppm just below the fly ash/clay interface to 0.019 ppm in the bedrock. Boron concentrations followed the same trend dropping from 14.2 to 3.2 ppm over the same distance. Selenium was not detected in any piezometer of Nest #5.

Even though the arsenic and boron profiles are consistent with the presence of a contaminant front, past experience has indicated that concentration values tend to change significantly with subsequent purging and sampling periods.

4.3.5 Comments

Both arsenic and boron, at concentration levels above background, have been detected in several overburden and bedrock piezometers below the ash lagoon. Although some of these high levels have persisted through the rounds of sampling and testing, concentrations did tend to decrease. The exceptions to this are some arsenic concentrations just below the fly ash/clay interface and boron concentrations at Nest #2, which have tended to increase. It is apparent from these fluctuations that three rounds of purging and sampling were not sufficient to obtain stable concentration values for arsenic and boron.

Some exceptionally high arsenic concentrations have been measured in certain piezometers below the ash lagoon. These high levels are up to an order of magnitude greater than existing levels measured within the ash lagoon. Two possibilities may explain these high values: 1) the analyses are incorrect or 2) significantly higher levels of arsenic are present near the bottom of the ash lagoon where more stagnant flow conditions persist. The presence of these high values, in piezometers located several metres below the bottom of the ash lagoon, may be explained in three different manners: 1) the piezometer intakes were contaminated with fly ash and/or fly ash leachate during installation; 2) a fly ash leachate front, with initially high arsenic concentrations, has migrated into the clay overburden; 3) fly ash leachate, with initially high arsenic concentrations, has found preferential pathways into the piezometer intakes via open fractures or gaps in the backfill material. With respect to option one above, several more rounds of flushing may eventually help correct the problem. Concerning option two, only Nest #3 possesses the hydraulic characteristics which could lead to rapid plug flow. The tendency of arsenic to be heavily adsorbed onto clay particles/8/, would have to be ignored in this case. In the case of option three, significant transport distances are possible within small continuous fractures if adsorption is again ignored. However, horizontal stresses within the overburden would tend to keep fractures closed.

It is interesting to note that, after the initial sampling stage, selenium concentrations dropped to below detection limits in all cases.

4.4 Analysis of Mixing

A convenient method of visually representing major-ion chemistries is through the use of the Piper diagram. In this trilinear diagram, shown in Figure 2, cation and anion concentrations are plotted as per cent equivalents. In this manner, the cation and anion composition of any sample is represented

as one point on each of the three portions of the diagram. The left hand triangle represents major cation composition and the right hand triangle represents major anion composition of any given sample. The quadrilateral represents the distribution of all major ions together. One of the advantages of this type of graphical representation is that waters of the same family, having similar major ion compositions but different total concentrations, will plot in the same area of the Piper diagram. Another advantage of the Piper plot is that solutions created by mixing of two waters from different sources will plot on a straight line joining the two points (Freeze and Cherry, 1979). The percentage of mixing is represented by the relative position of the solution between the two end members.

Figure 2 represents the major cation/anion concentrations of groundwater samples obtained by Golder Associates (1989) from properties to the east and north of Nanticoke TGS. These samples were taken from both overburden and bedrock piezometers. The dominant cation in these waters is calcium and the dominant anion is sulphate. Bicarbonate anion appears to be more common in the bedrock groundwater.

The major ion composition of background waters from Nests #1 and #6 are plotted in Figure 3. The chemical data plotted in this figure are from the July 27, 1988 sampling. The composition of cations and anions from these waters is similar to that for groundwater from east and north of the Nanticoke property. Figures 2 and 3 are therefore good representations of background ionic composition of overburden and bedrock groundwaters. The cationic composition is the most consistent.

The major ion composition of fly ash leachates, sampled from standpipe and bundle piezometers within the ash lagoon, is plotted in Figure 4. The two major differences between the compositions of ash leachate and groundwater are: 1) magnesium is virtually absent from the cation composition of ash leachate and, 2) chloride ion is present in minor concentrations in ash leachate. Since the most significant difference in composition is with the cations, mixing of ash leachate with groundwater should be more readily detectable by examining points within the "cation" triangle.

Most of the piezometers installed below the ash lagoon were isolated with bentonite plugs and backfilled up to the ash/clay interface with a cement or cement/bentonite grout. If groundwater comes into contact with the grout and is subsequently sampled, the major ion composition will be dominated by potassium plus sodium, and pH values will range between 11 and 12. This sample will tend to plot near the right-hand corner of the "cation" triangle on a Piper plot.

The results of water sampling and testing of Nests #2, 3, 4 and 5 on July 27, 1988, are plotted in Figures 5, 6, 7 and 8 respectively.

The major cation compositions of overburden and bedrock waters sampled from Nest #2, are similar to that of ash leachate or a mixing of leachate and groundwater. However, the anion compositions of samples from piezometers 2-1, 2-3 and 2-4 include more bicarbonate ion than in either ash leachate or overburden groundwater. This type of composition is more representative of surface water, an example of which is given in Figure 9. The chemical data for surface water was obtained from Hickory Creek by Golder Associates/7/.

The major ion compositions of samples from Nest #3 are plotted in Figure 6. The major cation composition of sample 3-4 appears to represent mixing of ash leachate and overburden groundwater. Piezometer 3-4 is located just below the ash/clay interface. The cation compositions of samples 3-2 and 3-3 do not appear to represent a straightforward mixing with ash leachate. Previous samples from 3-2 have plotted in the region of overburden groundwater.

The major ion compositions of samples from Nest #4 are plotted in Figure 7. Samples 4-1, 4-5 and 4-6 are clearly representative of overburden or bedrock groundwater. Samples 4-2, 4-3 and 4-4 do not plot as ash leachate or groundwater or a mixture of the two. In fact, these samples may be more representative of waters contaminated with cement grout.

The major ion compositions of samples from Nest #5 are plotted in Figure 8. These results are from only one round of sampling and testing. Samples 5-5 and 5-6, collected from just below the ash/clay interface, plot in the region of ash leachate. The remaining samples from 5-1 to 5-4 may represent groundwater contaminated with cement grout but not with ash leachate.

In conclusion, several samples collected from below the ash lagoon are not representative of mixing between groundwater and ash leachate alone. It has been postulated that some of the piezometers still contain water which has been contaminated by cement grout during installation. In some cases, fly ash leachate may have mixed with grout contaminated water which makes interpretation very difficult.

Water samples containing arsenic concentrations above background and also plotting near the region of ash leachate on a Piper diagram, are from the following: 2-4, 2-1, 3-4, 5-6 and 5-5. All of these samples, with the exception of 2-1, were collected from piezometers located immediately below the fly ash/clay interface. This may serve as evidence that ash leachate has migrated approximately a metre into the overburden. The remaining piezometer water samples containing elevated arsenic concentrations are not representative of a mixing between local groundwater and fly ash leachate. Consequently, these water chemistries cannot be reliably interpreted as ash leachate contaminating the local groundwater.

5.0 PORE WATER SQUEEZING

In an attempt to eliminate uncertainties associated with water samples collected from piezometers, pore water was squeezed from undisturbed clay cores sampled from below the ash lagoon. Analysis of the pore water would provide information on the extent of ash leachate migration into the overburden matrix.

The results of all overburden pore water analyses are plotted in Figures 10 to 17. In these figures, individual element concentrations from three different profiles are plotted versus depth below the fly ash surface. The results plotted as Nest 5a were obtained from sampling the overburden in the vicinity of Nest #5 in September, 1987. The results plotted as Nest 4 and Nest 5b were obtained from overburden profiles near Nests #4 and #5 respectively in October, 1988. The profiles from the vicinity of Nest #5 start at a greater depth than the profile near Nest #4. The fly ash/clay interface at Nest #4 is at an approximate elevation of 186.6 m ASL or 1.8 m higher than the designed lagoon bottom elevation of 184.8 m ASL. The original ground surface in the vicinity of Nest #4 was apparently not graded to the design elevation. Therefore, the complete thickness of weathered clay crust must still remain. The elevation of the fly ash/clay interface at Nest #5 is at an approximate elevation of 184.3 m ASL. Up to 3 m of weathered clay crust could have been removed from this area, based on original topographic elevations.

In Figures 10 to 17, the following cations and anions are plotted: calcium, magnesium, sodium, potassium, chloride, sulphate, boron and strontium. Because of the small volumes of sample collected from pore water squeezing, alkalinity and trace element concentrations were not determined.

Most of the profiles, aside from those for chloride and boron, show a trend of increasing concentrations with depth. This depletion of most major cations and anions near the ground surface is consistent with the presence of a weathered/leached horizon known to exist throughout the Nanticoke area. The exception to this are the chloride concentration profiles labelled Nest 5a and 5b which do not show any obvious trend with depth and the chloride profile from Nest #4 which shows a distinct decrease in concentration with depth. This profile does not correlate well with the presence of a weathered crust, from where soluble chloride should have been depleted. The top 1 metre of overburden near Nest #4 may have been contaminated by some chloride-rich leachate not originating from fly ash.

The calcium, magnesium, sodium and sulphate concentrations for profile 5B are significantly higher than those for profiles 4 and 5a. The magnitudes of these high concentrations are however within the range of values recorded in background waters as listed in Table VI. The wide range in concentrations is indicative of the heterogeneous geochemical conditions which exist in the clays and clay tills of the Nanticoke area.

The results of the water analyses from piezometer Nest #5 are plotted in Figures 10 to 17 for comparison purposes. It has been noted in a previous section that the major cation composition of waters sampled from Nest #5 is not indicative of overburden groundwater. The top two piezometers in fact, appear to represent fly ash leachate cation composition. The most interesting feature of these plots is that the potassium and boron concentrations measured in the piezometer waters are significantly higher than those measured in adjacent pore water samples. In fact, the potassium concentrations are up to an order-of-magnitude greater in the piezometers than in the pore waters. This is another indication that the water in the piezometers does not originate from the surrounding formation.

The boron profiles from the vicinity of Nest #5 are plotted in Figure 16. Both of these profiles show levels of boron above background down to an approximate depth of 13.5 m, or 2 m below the ash/clay interface. Based on a local hydraulic conductivity of 4×10^{-7} cm/s and a hydraulic gradient of 0.7, as reported by Vorauer (1989), and excluding adsorption by clay particles, it is possible that boron may have migrated down 2 m within the lifetime of the ash lagoon. The boron concentrations measured in the pore waters near Nest #5 remain, in general, below the ODWO limit of 5 mg/L. No elevated levels of boron were measured in the pore waters near Nest #4.

Figures 18, 19 and 20 are partial Piper plots of chemical analyses from profiles 4, 5a and 5b respectively. Complete Piper plots could not be made in these cases because of the lack of alkalinity measurements. In general, based on the major cation compositions plotted in Figures 18 to 20, the pore waters from under the ash lagoon are representative of background waters as plotted in Figure 2. Samples 2, 3 and 4, from profile 4, appear to plot on a straight line which would connect the cation compositions of groundwater and ash leachate. These three samples represent the top 1.4 m of overburden below the ash/clay interface, where mixing between groundwater and ash leachate may have occurred.

Pore water squeezing from clay cores, obtained in the vicinities of Nests #4 and #5, has provided the opportunity to measure the actual chemistry of overburden pore waters below the ash lagoon. The concentration profiles of major cations and anions are indicative of a weathered/unweathered profile where values increase with depth. Elevated boron concentrations have been detected in the overburden down to a depth of 2 m in the vicinity of Nest #5. In terms of detecting leachate migration from a waste impoundment into a low permeability medium, the pore water squeezing technique is definitely more reliable than the installation of piezometers for sampling. However, because of the low volumes of water extracted from clayey materials, not all elements of interest can be analyzed for. Once a general understanding of the major ion chemistry of the pore waters is developed, only the concentrations of indicator elements such as boron, arsenic and selenium need be determined.

6.0 BULK ANALYSES FOR ARSENIC AND SELENIUM

Soil samples submitted for bulk analysis of arsenic and selenium were from: 1) outside of the ash lagoon at Nest #1 from a depth of 8.5 m below ground surface; 2) under the ash lagoon at Nest #2 from depths of approximately 8, 11 and 14 m below the ash surface; 3) under the ash lagoon at Nest #3 from depths of approximately 11.9 and 18.9 m below the ash surface. Two chemical analysis methods were used for comparative purposes: i) neutron activation (NAA) and ii) acid digestion followed by atomic adsorption spectroscopy (AAS). The results of these analyses are provided in Table VIII.

From bulk elemental analyses of Nanticoke fly ashes /8/, arsenic concentrations range from 46 to 61 mg/kg and selenium concentrations range from 0.8 to 10 mg/kg.

Soils sampled from Nest #1 outside of the ash lagoon represent background conditions. In these samples, bulk arsenic concentrations ranged from 3 to 5 ppm and selenium concentrations were below detection limits (<2 ppm for NAA and <0.1 ppm for AAS). This range of values compares well with arsenic and selenium levels in surface soils of the Nanticoke area reported by the Ministry of the Environment (1979). These soil samples were collected within a 40 km radius of Nanticoke TGS. Arsenic levels ranged from 1.5 to 6 ppm for the sampling period between 1978 and 1979. Selenium levels ranged from 0.14 to 1.12 ppm for the same period. Recommended phytotoxicology excessive levels for arsenic and selenium are 25 and 5 ppm respectively.

Analysis of soils from Nest #2 indicate that, within 10 mm of the fly ash/clay interface, arsenic levels range from 25 to 29 ppm and selenium levels range from 0.2 to 0.7 ppm. Below 10 mm, arsenic levels drop to below 10 ppm. At a depth of 11 m, arsenic levels range from 28.8 to 9.1 ppm and selenium levels are approximately 1 ppm. At a depth of 14 m below the ash surface, arsenic is at 5 ppm. The arsenic concentrations at 11 m appear to be excessively high. In fact, samples closer to the interface had less arsenic in them. However, both methods of analysis (NAA and AAS), and duplicate samples, did provide similar results. The soils at a depth of 11 m consist of remoulded clay which was used to backfill a creek valley during construction of the lagoon bottom. These samples may have been previously contaminated, which would explain the unusually high arsenic levels found 2.5 m below the ash/clay interface.

At Nest #3, arsenic levels are very consistent with depth. From the ash/clay contact to a depth of 60 mm, arsenic levels range between 4.8 and 6.5 ppm. The selenium concentration at the interface is equal to 0.3 ppm. At a depth of approximately 19 m below the ash surface, arsenic levels average 5.6 ppm and selenium levels are at 0.3 ppm. No high levels of arsenic or selenium have been detected in the soils of Nest #3, even though fly ash has been in contact with the clay of this area since the start of lagoon operations. However, the fly ash/clay interface was difficult to identify at this location because of the presence of cobbles and wood. The soils may have been sampled from a greater depth than the actual ash/clay interface.

So far, the bulk trace element chemistry data collected in this study has proven inconsistent. Whereas excess levels of arsenic have been detected sporadically to depths of 2.5 m into the remoulded clay of Nest #2, only background levels of arsenic have been detected at the assumed level of the interface at Nest #3. A more detailed program of sampling and testing would have to be undertaken to complement the findings of this initial investigation, before any estimates of diffusion coefficients or penetration distances can be made.

7.0 SUMMARY

Based on hydraulic head monitoring results reported previously /1/, the Nanticoke TGS ash lagoon has had a definite hydraulic impact on the underlying groundwater system. The ash lagoon has also had an impact on the quality of this underlying groundwater system, however, the extent of impact remains difficult to assess.

Elevated levels of arsenic and boron have persisted in several overburden and bedrock piezometers through a maximum of three rounds of purging, sampling and testing (applicable only to nests #2 and 3). Whether these elevated concentrations are representative of formation groundwater may be questioned for the following reasons: 1) some of these values are anomalously high and their trends with depth do not represent the scenario of a contaminant front moving into the overburden; 2) in several cases, estimated groundwater matrix velocities are not high enough to have lead to the significant transport distances implied; 3) the distribution of major ion concentrations in several water samples are not solely representative of a mixing between fly ash leachate and overburden groundwater, which indicates that some degree of contamination may have occurred from a separate source.

In general, overburden piezometers which contain both water representative of ash leachate and excess levels of arsenic, are located immediately below the fly ash/clay interface at nests #2, 3 and 5. The bottom of these piezometers are 1.8 m, 1.2 m and 0.9 m below the ash/clay interface respectively.

A total of 4 piezometers are located within the shallow bedrock aquifer below the ash lagoon. This unit is the only significant source of groundwater in the area and is therefore the only unit where the MOE's Reasonable Use Criteria should apply /7/. It is important to note that in previous hydrogeologic investigations in the Nanticoke area /1,7/, it has been determined that the direction of groundwater flow within the shallow bedrock unit is predominantly towards the south. Consequently, bedrock groundwater below the Nanticoke TGS moves directly towards Lake Erie without intersecting any water supply wells. On the last sampling and testing period, bedrock piezometers at Nests #2 and 5 had arsenic and boron levels in excess of the Reasonable Use Criteria limits as established previously by Golder Associates /7/. These limits are 0.013 and 1.3 ppm for arsenic and boron respectively. Following the last sampling of bedrock piezometer 2-1, the arsenic concentration was equal to 0.014 ppm and boron was 11.1 ppm. At piezometer 5-1, arsenic was found

at 0.019 and boron at 3.17 ppm. These last values were obtained following only one round of purging and sampling at nest #5.

The bedrock piezometer at nest #4 did not reveal excess levels of arsenic or boron.

Because of the possible contamination of piezometer intakes during installation, the geochemical data obtained to date from sampling, must be considered largely unreliable. Further rounds of well purging and sampling may lead to more consistent and representative water chemistries. The results of the pore water extraction tests are more satisfactory. The cation and anion profiles obtained in the vicinities of nests #4 and #5 reveal the existence of a weathered/leached horizon near the original ground surface. Most of the major cation concentrations were representative of overburden groundwater. The boron profiles from the vicinity of nest #5 were the only indications of fly ash leachate migration into the overburden. Excess levels of boron were detected up to a depth of 1.5 m below the ash/clay interface.

Because of the relative consistency of the pore water extraction data obtained during this study, additional soil cores from within and around the Nanticoke ash lagoon should be obtained and tested. This would help to confirm the areal extent of ash leachate migration into the overburden soil structure. In this case, the majority of the chemical analyses could be restricted to minor and trace elements such as boron, arsenic and selenium. At the same time, portions of the soil cores could be submitted for bulk analysis of arsenic.

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TABLE I

NANTICOKE FLY ASH LAGOON PIEZOMETER ELEVATION

Piezometer No.	Ground Elevation (m ASL)	Top of Pipe Elevation (m ASL)	Piezometer Elevation (Top of Intake) (m ASL)	Piezometer Elevation (Bottom) (m ASL)
1-4	184.88	185.38	180.61	178.79
1-3	184.87	185.75	178.92	177.25
1-2	184.92	185.75	180.35	175.28
1-1	184.92	185.79	174.25	172.33
2-6 (fly ash)	192.55	193.45	189.50	188.28
2-5 (fly ash)	192.60	193.40	186.50	185.28
2-4	192.61	193.48	183.46	182.55
2-3	192.60	193.70	181.93	180.71
2-2	192.66	193.74	178.94	177.72
2-1	192.61	193.47	175.84	174.09
3-6 (fly ash)	197.95	198.56	194.59	193.38
3-5 (fly ash)	197.92	199.07	190.29	188.78
3-4	197.92	198.71	185.72	184.51
3-3	197.80	198.75	182.55	181.34
3-2	197.93	198.93	179.64	178.42
3-1	197.92	198.78	177.19	175.06
4-6	196.99	197.84	185.19	184.17
4-5	196.96	197.22	182.86	182.02
4-4	197.01	197.77	181.79	181.03
4-3	196.96	197.71	180.77	180.16
4-2	197.04	197.87	178.92	178.31
4-1	197.05	197.97	178.04	176.67
5-6	195.96	196.89	184.0	183.39
5-5	195.90	196.76	182.87	182.26
5-4	195.88	196.65	181.25	180.64
5-3	195.86	196.74	179.85	179.24
5-2	195.88	196.83	178.51	177.90
5-1	195.87	196.75	175.87	174.35
6-7	189.02	189.79	188.05	187.63
6-6	189.00	189.81	186.54	186.08
6-5	189.02	189.78	184.99	184.53
6-4	189.01	189.80	183.48	183.02
6-3	189.03	189.79	181.91	181.45
6-2	189.05	189.82	181.10	180.43
6-1	189.04	189.78	180.56	178.83
6-T1	189.07	189.88	183.55	183.09
6-T2	188.99	189.89	182.52	183.06
6-T3	189.13	189.83	183.56	183.10

TABLE II

NANTICOKE TGS ASH LAGOON - PIEZOMETER WATER SAMPLES

SAMPLING DATE: JANUARY 26, 1987

Sample	Ca	Mg	Na	K	Mn	Sr	Si	As	Se	B	SO4=	Cl-	pH	HCO3-	CO3=	OH-	Cond	TDS	CAB
#	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	units	mgCaCO3/L	mgCaCO3/L	mgCaCO3/L	uS/cm	mg/l	%
1-4	52	160	79	7.4	0.1	3.2	15	<0.001	0.003	0.28	238	4	7.48	729	<5	<5	1400	990	-0.68
1-3	89	200	78	11	0.42	4.9	19	0.001	0.005	0.28	622	5	7.74	681	<5	<5	1760	1428	-4.18
1-2	308	310	71	12	0.55	9.1	22	<0.001	0.006	0.23	1700	4	7.66	476	<5	<5	2770	2842	-0.85
1-1	184	320	111	7.7	0.14	9.1	15	<0.001	0.006	0.45	1440	9	7.28	620	<5	<5	2720	2553	-2.53
2-6	136	<0.1	26	18	<0.05	17	4.7	0.006	0.015	0.31	18	29	11.81	<5	58	406	1570	486	-8.29
2-5	186	0.6	66	24	<0.05	6.1	6.8	0.010	0.028	6.7	590	28	10.42	<5	37.2	15.1	1100	913	-3.51
2-4	53	3.4	68	37	<0.05	4	4.3	0.029	0.005	1.17	34	24	8.16	315	<5	<5	690	487	-5.90
2-3	326	110	216	8.4	4.8	2.2	38	0.002	0.005	2.43	610	17	7.16	839	<5	<5	2110	1534	7.66
2-2	109	0.1	74	14	<0.05	2.5	8.5	0.008	0.006	0.58	85	26	11.85	<5	88	366	1470	532	-8.51
2-1	192	89	76	12	0.52	3.9	11	0.064	0.006	7.6	16	9	7.09	360	<5	<5	1650	1385	44.97
3-6	116	0.1	59	43	<0.05	6.4	11	0.025	0.023	0.83	280	38	11.49	<5	25.1	158	1260	493	-4.30
3-5	54	3.7	9.4	3.5	<0.05	0.86	1.5	0.010	0.009	1.12	126	14	8.32	41.7	<5	<5	371	194	-4.83
3-4	47	7.5	8.9	2	<0.05	0.27	3	0.003	0.010	0.19	35	14	7.84	121	<5	<5	317	205	-2.06
3-3	46	10	233	6.1	<0.05	1	6	0.105	0.006	3.86	565	17	9.07	457	<5	<5	1310	980	-22.92
3-2	169	240	149	5.5	0.39	5.4	18	0.017	0.003	2.1	1430	9	7.65	456	<5	<5	2370	2387	-5.88
3-1	125	0.1	113	66	<0.05	4.4	20	0.010	0.019	1.25	420	28	11.55	<5	94	373	1600	924	-16.52

TABLE III

NANTICOKE TGS ASH LAGOON - PIEZOMETER WATER SAMPLES

SAMPLING DATE: JUNE 17,1987

Sample	Soil	Ca	Mg	Na	K	Fe	Mn	Sr	Si	As	Se	B	SO4=	Cl-	F-	pH	Eh	Tot.Akl.	Cond	CAB
#	Type	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	units	(mV)	mgCaCO3/L	uS/cm	%
1-4	CLAY	50.9	175	88.3	6.85	<0.05	0.11	2.84	5.25	<0.002	<0.002	0.1	229	4.4	0.61	7.76	433	732	900	3.51
1-3	TILL	84.8	230	83	8.8	<0.05	0.27	4.19	13.8	<0.002	<0.002	0.09	599	3.8	0.85	7.75	429	700	1250	0.77
1-2	TILL	275	331	74.4	9.6	<0.05	0.35	5.57	16	<0.002	<0.002	0.23	1405	3.96	1.94	7.58	430	454	1770	7.23
1-1	B/R	176	342	120	6.94	0.73	0.09	6.17	14	<0.002	<0.002	3.99	1224	7.91	2.67	7.44	-	521	1700	7.89
2-6	ASH	104	0.045	49.4	31.9	<0.05	<0.02	12.7	3.1	<0.002	<0.002	0.23	62.3	30.9	0.22	11.83	222	334	1200	-4.06
2-5	ASH	265	1.21	79.6	38.7	<0.05	<0.02	6.02	3.85	0.005	0.0025	13.2	586	29.9	0.43	10.37	246	84	1080	9.39
2-4	CLAY	194	6.88	51.9	19.7	6.07	0.36	2.64	5.75	0.0035	<0.002	2.26	92.5	31.1	0.37	7.07	219	413	800	8.08
2-3	CLAY	253	96.3	339	12.5	25.9	3.25	1.71	20.5	0.0024	<0.002	7.5	267	20.9	1.12	7.2	189	375	730	44.59
2-2	TILL	25.9	6	68.6	14	<0.05	<0.02	1.45	5.35	0.0065	<0.002	0.51	117	35.6	0.36	9.9	229	47.2	400	7.82
2-1	B/R	235	283	132	16.6	0.77	0.45	3.91	8.5	0.0035	<0.002	9.36	445	10.6	0.91	7.48	244	752	1750	25.19
3-6	ASH	79.5	0.273	103	71.6	<0.05	<0.02	3.84	9.5	0.0187	0.0093	0.53	232	45.8	0.22	11.67	402	187.4	1110	2.14
3-5	ASH	110	0.468	12.3	5.7	<0.05	<0.02	2.19	12.9	0.0126	<0.002	2.2	213	15.8	<0.1	10.76	391	55.6	450	1.77
3-4	CLAY	111	42.4	149	3.68	0.21	0.85	1.05	9.75	0.0173	<0.002	3.1	447	18.4	0.61	7.28	276	235	900	3.57
3-3	CLAY	35	8.15	151	5.69	<0.05	<0.02	0.57	12.5	0.0275	<0.002	1.84	328	13.4	0.61	8.96	413	58	630	4.36
3-2	TILL	131	283	178	5.84	<0.05	0.33	3.24	12.8	0.0037	<0.002	1.14	945	7.2	1.58	7.41	202	598	1680	8.44
4B-6	ASH	114	0.07	10.2	5.06	<0.05	<0.02	2.16	7.35	0.0051	0.013	3.9	121	11.6	0.1	11.29	199	132		6.64
4B-10	ASH	109	0.082	10.4	5.27	<0.05	<0.02	2.28	10.8	0.0073	0.0123	2.44	142	14	0.14	11.04	-	108		4.52
4B-12	ASH	93.7	0.091	11.6	5.2	<0.05	<0.02	2.14	8.75	0.009	0.0099	4.01	113	12.6	0.16	11.04	193	113		3.43
4B-14	ASH	102	0.236	12.3	6.35	0.36	<0.02	2.52	5.15	0.007	0.0082	3.25	91.6	11.6	0.1	11.24	-	152		4.80
4B-16	ASH	100	0.383	13.5	7.47	0.54	<0.02	2 92	5.5	0.0056	0.0067	3.15	87.7	10.4	<0.1	11.12	193	137		8.82
4B-18	ASH	96.3	1.63	15.3	5.9	2.32	0.04	2.32	7.05	0.01	0.0078	3.34	134	13.2	0.16	11.03	-	90		7.40
4B-20	ASH	97.8	0.858	17.5	6.45	1.03	<0.02	3.07	5.5	0.0063	0.0076	3.69	138	12.4	0.3	11	-			
4B-22	ASH	81.3	2.23	12.6	3.44	1.24	0.02	1.48	4.55	0.0112	0.0025	2.29	141	13.9	0.18	10.55	202			

NB: Samples labelled 4B-x refer to bundle piezometers at Nest #4,
where x = depth of bundle intake below ash surface.

TABLE IV

NANTICOKE TGS ASH LAGOON - PIEZOMETER WATER SAMPLES

SAMPLING DATE: NOVEMBER 5, 1987

SAMPLE	SOIL	Ca	Mg	Na	K	Fe	Sr	Si	As	Se	B	SO4=	Cl-	pH	Tot. Alk.	CAB
#	TYPE	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	units	mgCaCO3/L	%
4-6	CLAY	145	198	165	3.2	<0.05	2.9	6.4	0.127	0.002	3.26	838	14.8	7.71	336	11.20
4-5	CLAY	93	240	211	7.8	-	3.1	8.84	0.047	0.003	* 0.79	869	13.9	7.8	476	9.32
4-4	CLAY	33	33	325	8.5	<0.05	0.9	10.1	0.240	0.020	1.72	406	6.61	9.56	192	19.99
4-3	CLAY	90	2.1	415	20	<0.05	1.4	15.8	0.020	0.008	0.58	706	13.4	10.3	89	15.89
4-2	TILL	270	0.8	202	59	<0.05	2.32	5.42	<0.001	0.003	0.2	52	16.4	12.06	766	17.12
4-1	B/R	160	300	150	10	<0.05	1.02	6.73	<0.001	<0.001	0.73	1050	6.15	7.25	535	9.30

TABLE V

NANTICOKE TGS ASH LAGOON - PIEZOMETER WATER SAMPLES

SAMPLING DATE: JULY 27, 1988

SAMPLE	Ca	Mg	Na	K	Sr	Si	As	Se	B	SO4=	Cl-	pH	Tot.Akl.	Cond.	TDS	CAB
#	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	units	mgCaCO3/L	uS/cm	mg/l	%
1-4	52.8	170	93.9	5.92	3.78	6.6	<.003	<.003	<0.5	208	0.98	7.40	809.1	1450	1035	0.76
1-3	79	205	74.1	7.22	3.74	8.3	<.003	<.003	<0.5	610	1.35	7.60	717.4	1780	1965	-5.60
1-2	282	326	72.6	9.02	5.80	9.0	<.003	<.003	<0.5	1535	4.22	7.35	481	2700	3890	3.00
1-1	147	255	99.4	5.9	4.89	7.0	<.003	<.003	<0.5	1205	9.02	7.25	650.6	2530	3460	-7.82
2-6	108	0.132	52.6	37.3	7.86	6.1	0.007	<.003	1.5	163	27.7	11.65	171.5	1210	585	6.38
2-5	229	0.583	68.9	36.5	5.33	2.2	0.008	<.003	12.8	550	36.4	9.25	46.7	1340	1200	6.92
2-4	290	18.5	65.3	22.2	2.69	7.6	0.020	<.003	6.03	410	4.11	6.65	460.3	1530	1460	4.14
2-3	269	93	238	12.8	2.15	11.9	<.003	<.003	15.3	330	29.6	6.85	1090.5	2380	1995	3.65
2-2	145	15.7	92.1	11.7	1.48	4.6	0.006	<.003	0.88	345	36	8.15	144.5	1140	1035	7.29
2-1	332	103	51.4	29.1	2.22	13.4	0.014	<.003	11.1	435	33.5	7.15	826.5	1980	2230	2.73
3-6	187	0.201	91.5	35.8	5.04	7.9	0.025	0.017	1.9	500	495	10.90	81.5	1360	1010	-29.22
3-5	114	0.445	15.1	6.71	2.13	5.6	0.020	<.003	2.1	210	15.9	10.75	62.8	595	450	3.78
3-4	138	52.8	122	2.95	1.17	9.4	0.019	<.003	2.54	290	16.6	7.45	487	1300	1090	1.11
3-3	61.7	14.9	102	7.22	0.98	5.4	0.113	<.003	2.9	350	15.5	8.10	48.7	919	750	1.29
3-2	78.3	129	215	4.64	2.12	10.3	0.007	<.003	0.62	698	10.7	7.65	502.5	1960	1920	-1.83
4-6	165	284	174	2.45	1.74	7.7	0.215	<.003	2.73	1045	17.5	7.65	606.7	2470	3195	6.58
4-5	110	391	246	7.37	2.44	8.2	0.014	<.003	0.52	1400	17.5	7.55	747.4	2960	4080	4.25
4-4	24.5	28.5	259	7.83	0.58	9.4	0.086	<.003	1.64	420	9.1	8.15	321.7	1450	965	-1.32
4-3	112	1.23	528	22.7	1.18	9.7	0.022	<.003	<0.5	1450	16.1	8.85	40.4	3000	2315	-3.65
4-2	206	0.168	238	49.1	2.34	3.0	<.003	<.003	<0.5	545	22.6	11.90	439.3	3120	1490	2.65
4-1	148	245	137	9.53	5.92	5.0	<.003	<.003	0.68	1055	7	7.25	546.4	2340	2990	0.98
4B-18	116	1.32	11.8	6.52	2.94	4.5	0.022	<.003	4.39	--	--	11.05	89.8	--	--	--
4B-22	59.5	10.6	8.16	1.98	0.77	3.0	0.052	<.003	0.99	117	11.5	8.80	65.8	421	260	2.05
4B-28	81.3	1.11	9.04	2.69	1.06	2.2	0.031	<.003	1.98	160	12.9	10.35	44.7	484	260	0.23

TABLE V cont'd

NANTICOKE TGS ASH LAGOON - PIEZOMETER WATER SAMPLES

SAMPLING DATE: JULY 27, 1988

SAMPLE	Ca	Mg	Na	K	Sr	Si	As	Se	B	SO4=	Cl-	pH	Tot.Akl.	Cond.	TDS	CAB
#	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	units	mgCaCO3/L	uS/cm	mg/l	%
5-6	256	23.8	71.6	12	3.60	<2	0.086	<.003	14.2	800	28	8.30	43.8	1500	1560	-0.46
5-5	315	39.9	158	14.9	4.00	2.3	0.068	<.003	11.9	1030	26	8.46	42.1	2070	2250	6.56
5-4	107	202	465	79.9	1.58	9.6	0.180	<.003	9.13	1595	19.3	7.95	325.9	3300	3495	4.68
5-3	173	206	612	336	3.44	4.8	0.052	<.003	4.23	2430	26.7	7.70	242.6	4780	5140	3.93
5-2	101	10.3	265	139	2.55	5.6	0.020	<.003	3.25	1055	25.4	9.50	86.5	2360	1740	-7.59
5-1	65.8	64.5	143	42.3	2.67	3.3	0.019	<.003	3.17	413	26	8.05	187.7	1360	1385	9.68
6-7	100	220	131	1.52	1.24	7.2	<.003	<.003	<0.5	1170	10.8	7.55	302.4	1850	2725	1.77
6-6	230	683	641	11	3.41	8.1	<.003	<.003	<0.5	3635	24.2	7.60	516.9	5300	7420	5.00
6-5	203	674	423	10.8	3.99	7.5	<.003	<.003	0.51	3255	17.8	7.50	642.8	4880	7270	1.89
6-4	173	521	371	11.2	3.85	7.7	<.003	<.003	0.53	2485	11.8	7.30	667.3	4090	5670	1.88
6-3	136	390	348	10.7	3.89	11.3	<.003	<.003	0.53	2040	10.8	7.50	579.4	3670	4800	-0.06
6-2	121	359	511	12.3	4.42	15.0	<.003	<.003	<0.5	2140	15.5	7.55	585.64	4170	4630	1.23
6-1	137	287	166	5.21	4.51	3.9	<.003	<.003	0.61	1285	10.4	7.30	468.64	2600	3380	1.86

TABLE VI

NANTICOKE TGS ASH LAGOON - BACKGROUND OVERBURDEN WATER CHEMISTRY
Data from Nest 1 & 6 combined with data from Golder Associates (42 samples)

	Ca	Mg	Na	K	Sr	As	Se	B	SO4	Cl	pH	HCO3
Average	206	591	243	9	6.05	<.001	<.001	0.39	2578	29.7	7.8[illegible]	655
Std Deviation	114.1	345	136	4	3.64	-	-	0.25	1521	-	0.54	156
Maximum	419	1400	641	17	11.9	-	.006 *	1.24	5420	732	8.43	987
Minimum	36.7	148	72	0.5	0.0	-	-	0.01	208	1	5.81	271

NANTICOKE TGS ASH LAGOON - BACKGROUND BEDROCK WATER CHEMISTRY
Data from Nest 1 & 6 combined with data from Golder Associates

	Ca	Mg	Na	K	Sr	As	Se	B	SO4	Cl	pH	HCO3
Average	202	435	174	9.1	7.0	<0.001	<0.001	0.7	1955	30.5	7.69	698
Std Deviation	99	257	61	3.8	2.5	-	-	0.4	1251	35.6	0.34	84
Maximum	445	944	306	15.6	11.9	.018 **	-	1.4	4440	173	8.21	806
Minimum	100	104	99	2.3	2.7	-	-	0.1	412	5.8	7.12	507
ODWO	250	-	20	-	-	0.050	0.010	5.0	500	250	-	-

NB: * Measured at location 13A in Golder Associates (1989)
** Measured at location 1-2 in January/87

TABLE VII

NANTICOKE TGS ASH LAGOON - ASH LEACHATE CHEMISTRY
Data obtained from standpipe and bundle piezometers within the ash lagoon (23 samples)

	Ca	Mg	Na	K	Sr	As	Se	B	SO4	Cl	pH	TDS
Average	119	1.2	33	18	4.3	0.014	0.008	3.3	217	22	10.8	666
Maximum	265	3.7	103	71.5	17	0.052	0.028	13.2	590	49.5	11.8	1200
Minimum	54	0.04	8.2	3.5	0.8	<0.002	<0.002	0.23	18	10.4	7.9	194

TABLE VIII

Bulk analysis results for Arsenic and Selenium

Sample type: 50mm diameter x 5mm thick, soil discs
Analysis methods: Neutron Activation (NAA) & Atomic Absorption Spectroscopy (AAS)

Location: Nest 2 (Ash/clay contact at 8.23 m BGL)
Sample Depth: 7.93 - 9.14 m BGL (clay backfill in creek valley)

Distance from Ash/Clay Contact (mm)	NAA [As] (ppm)	AAS [As] (ppm)	NAA [Se] (ppm)	AAS [Se] (ppm)
5	25	26.7	<2	0.7
11	28	29	<2	0.2
23		10.1		
34		5.1		
49		7.9		
69		9.8		

Location: Nest 2
Sample Depth: 11.0 - 11.58 m BGL (clay backfill in creek backfill)

Distance from Top of Sample (mm)	NAA [As] (ppm)	AAS [As] (ppm)	NAA [Se] (ppm)	AAS [Se] (ppm)
0	22	28.8	<2	1.1
5	20	21.1	<2	0.9
10		25.8		
15		9.1		

Location: Nest 2
Sample Depth: 14.02 - 14.63 m BGL (original clay/fill)

Distance from Top of Sample (mm)	NAA [As] (ppm)	AAS [As] (ppm)	NAA [Se] (ppm)	AAS [Se] (ppm)
0		5.1		
5		4.5		

Location: Nest 3 (Ash/clay contact at 12.2 m BGL)
Sample Depth: 11.89 - 12.5 m BGL

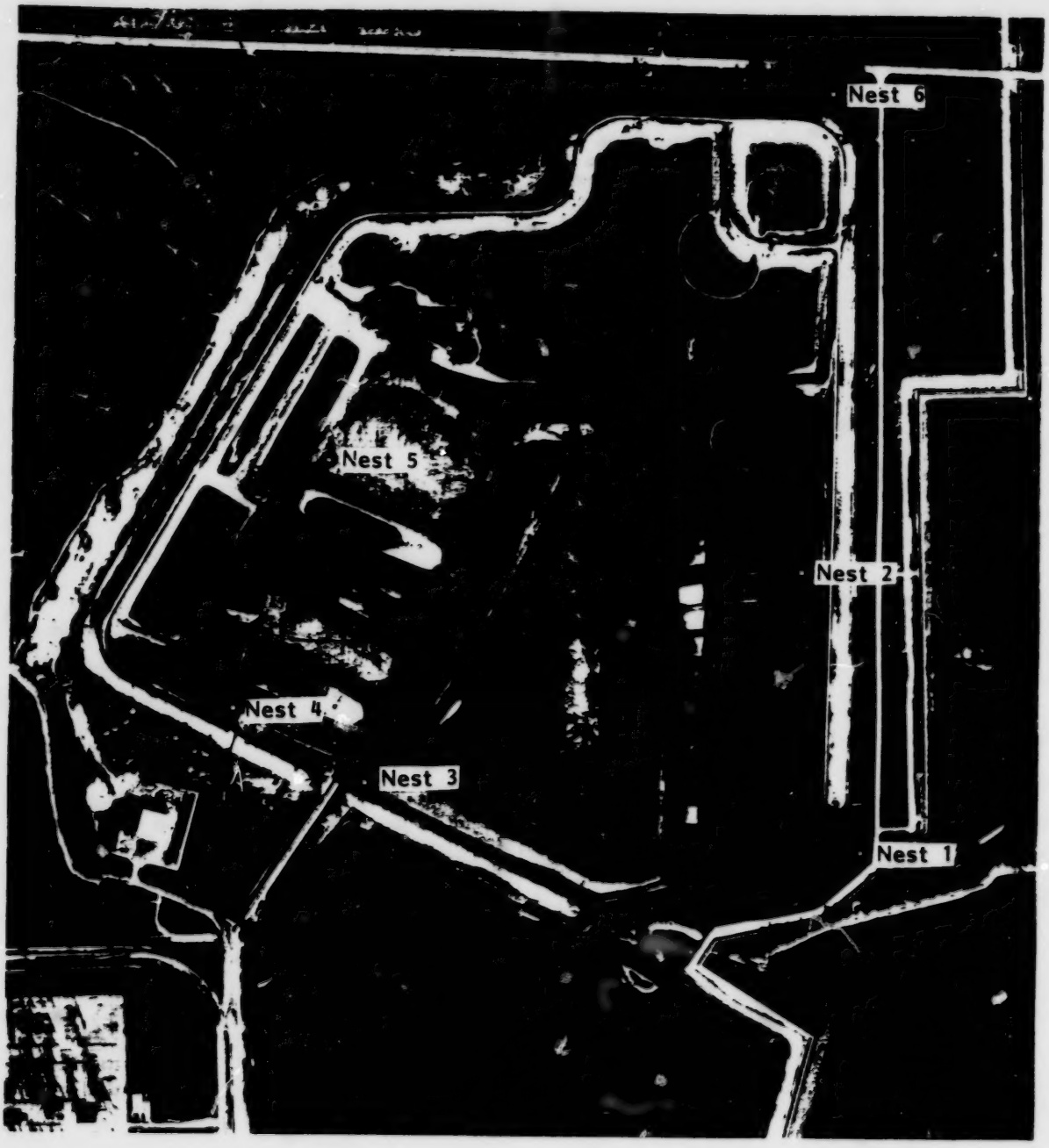
Distance from Ash/Clay Contact (mm)	NAA [As] (ppm)	AAS [As] (ppm)	NAA [Se] (ppm)	AAS [Se] (ppm)
5	5	5.2	<2	0.3
15		5.6		
24		6.5		
34		5.0		
44		4.8		
60		5.7		

Location: Nest 3 (Ash/clay contact at 12.2 m BGL)
Sample Depth: 18.90 - 19.51 m BGL

Distance from Top of Sample (mm)	NAA [As] (ppm)	AAS [As] (ppm)	NAA [Se] (ppm)	AAS [Se] (ppm)
0	5	5.3	<2	0.3
5	7	5.9	<2	0.3

Location: Nest 1 (outside of ash lagoon)
Sample Depth: 8.54 - 8.80 m BGL

Distance from Top of Sample (mm)	NAA [As] (ppm)	AAS [As] (ppm)	NAA [Se] (ppm)	AAS [Se] (ppm)
0	3	3.6	<2	<0.1
5	5	4.4	<2	<0.1



● PIEZOMETER NEST LOCATIONS

FIGURE 1

AERIAL PHOTO OF NANTICOKE TGS ASH LAGOON (1988)

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE AREA GROUNDWATER CHEMISTRY
- Background data obtained by Golder Associates
- Total of 29 overburden and bedrock piezometers

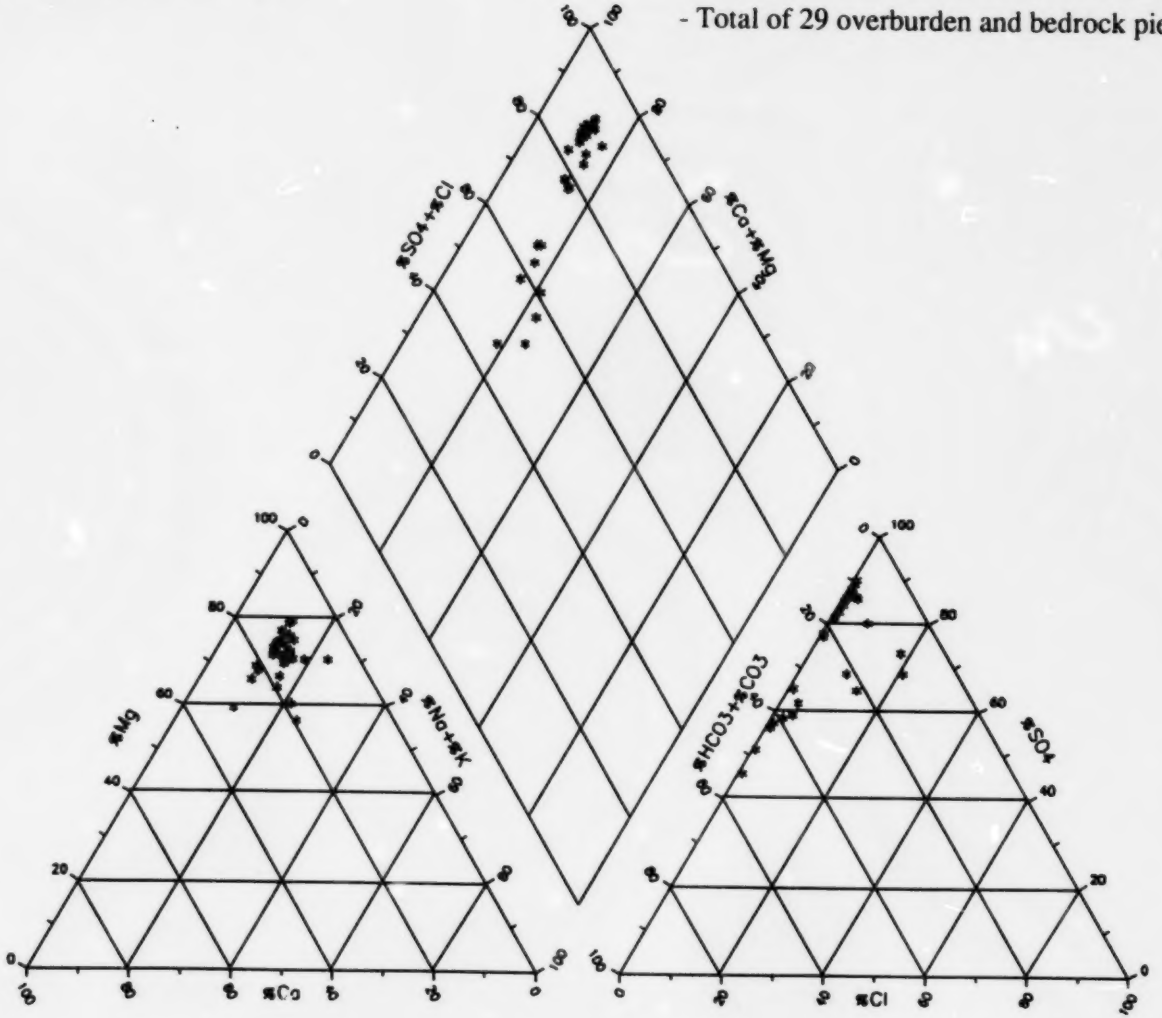


Figure 2

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE GROUNDWATER CHEMISTRY
- Background data obtained from Nests 1 & 6
in Aug./88

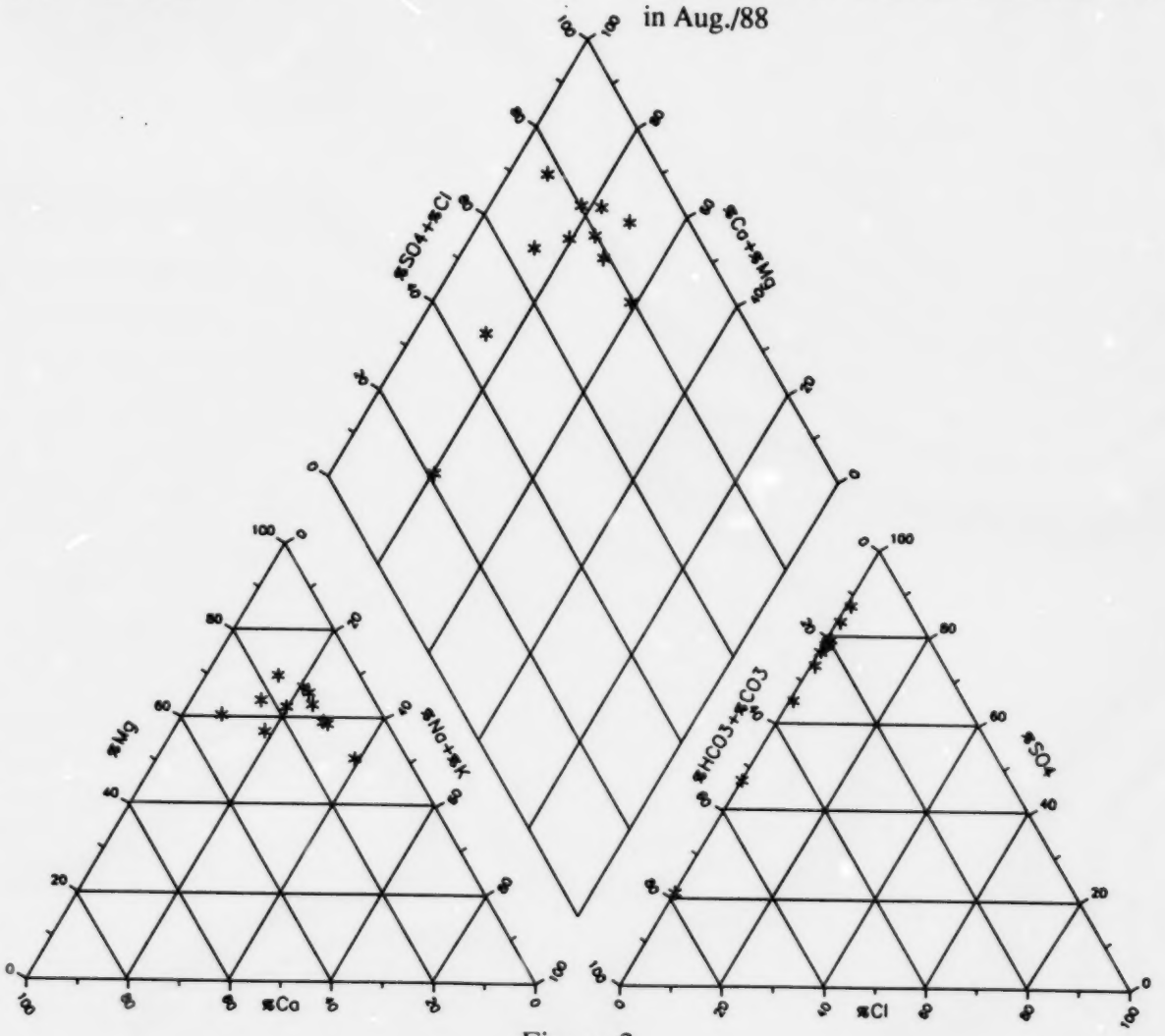


Figure 3

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE ASH LEACHATE CHEMISTRY
- Samples obtained from bundle and standpipe piezometers within the ash lagoon (Nests 2,3 & 4)

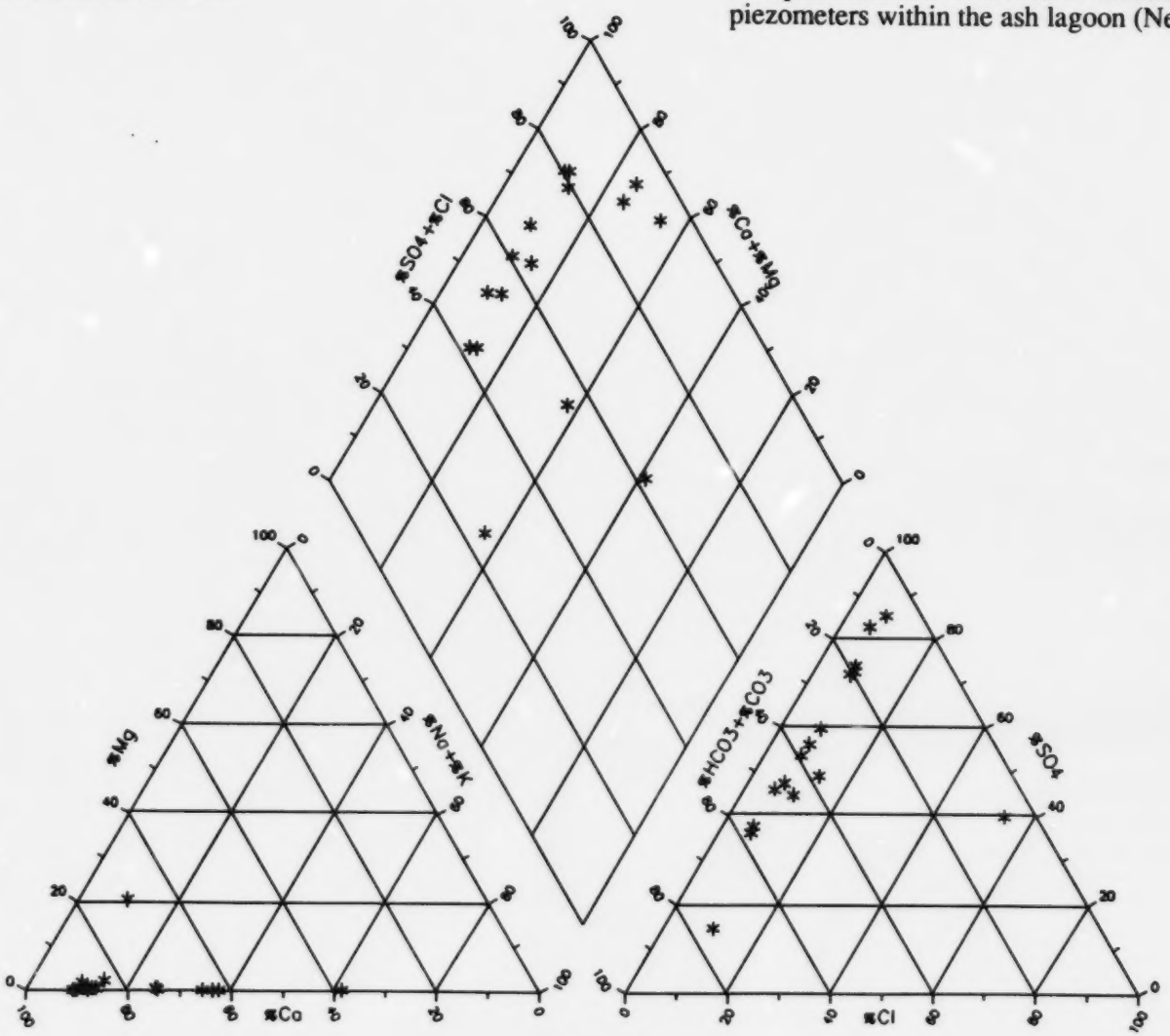


Figure 4

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE WATER CHEMISTRY
- Location : Nest 2 - overburden piezometers as numbered
- Sampled in Aug./88

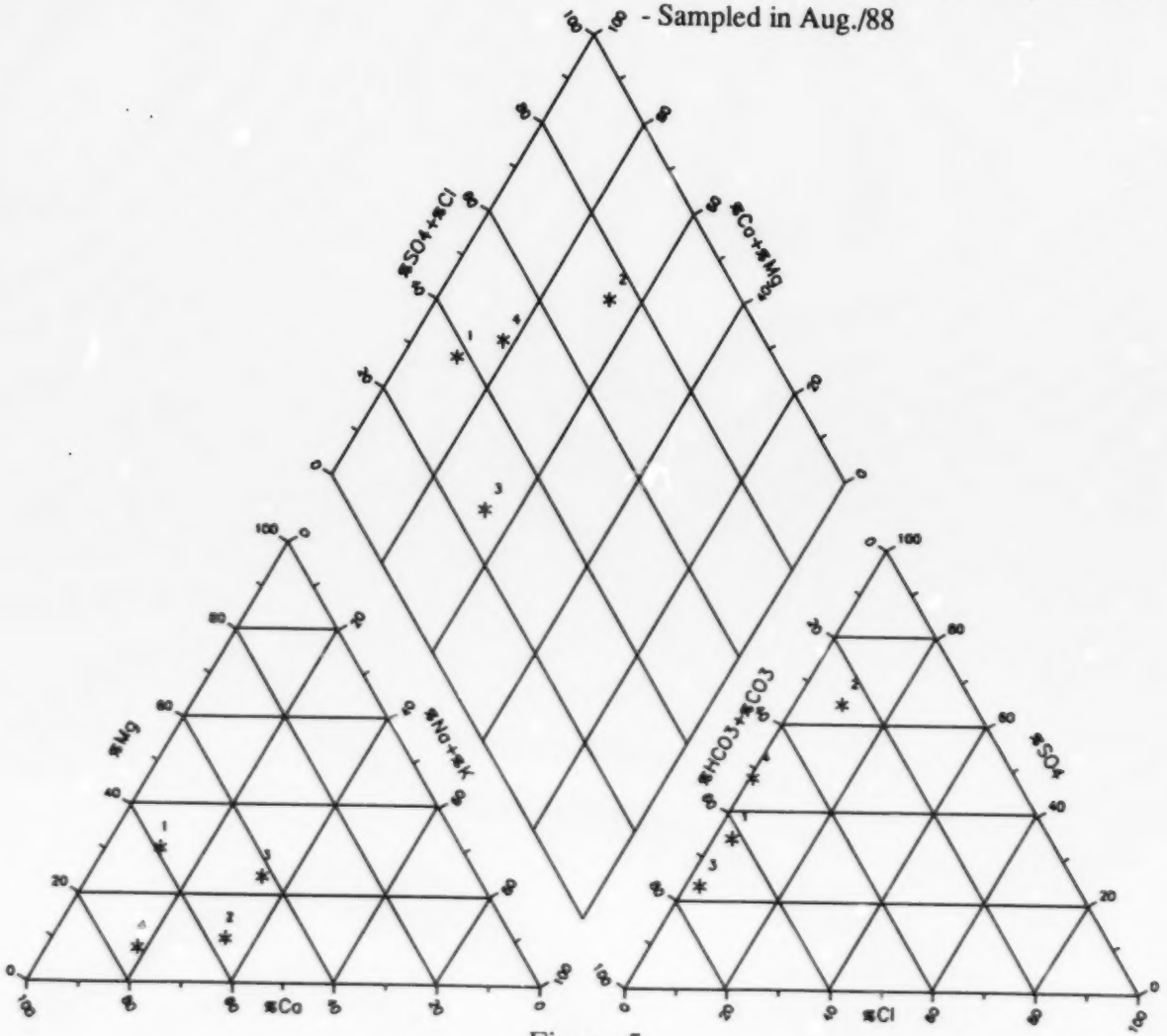


Figure 5

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE WATER CHEMISTRY
- Loaction: Nest 3 - overburden piezometers as numbered
- Sampled in Aug./88

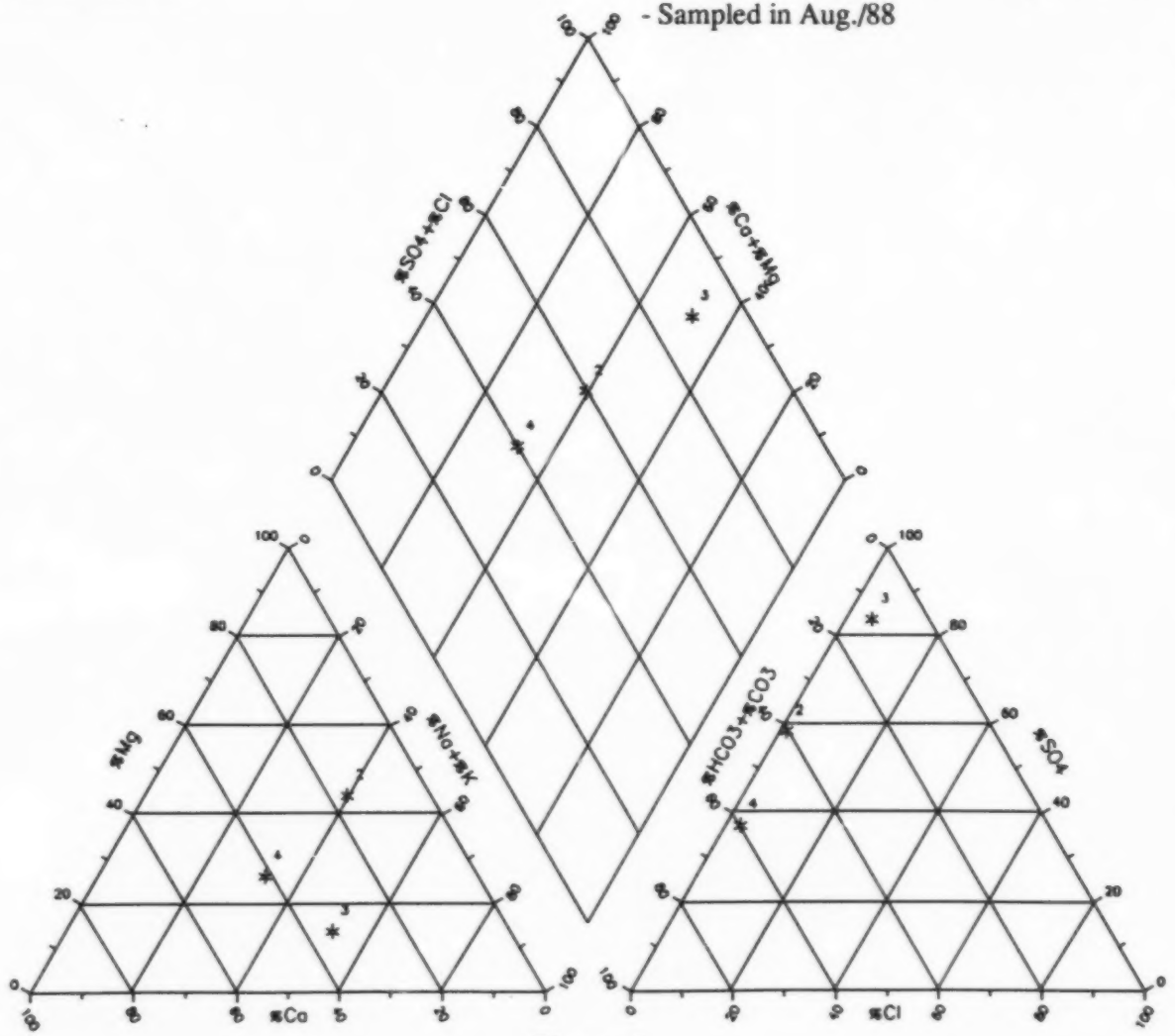


Figure 6

PIPER DIAGRAM
MAJOR ION DIAGRAM

NANTICOKE WATER CHEMISTRY
- Location: Nest 4 - overburden piezometers as numbered
- Sampled in Aug./88

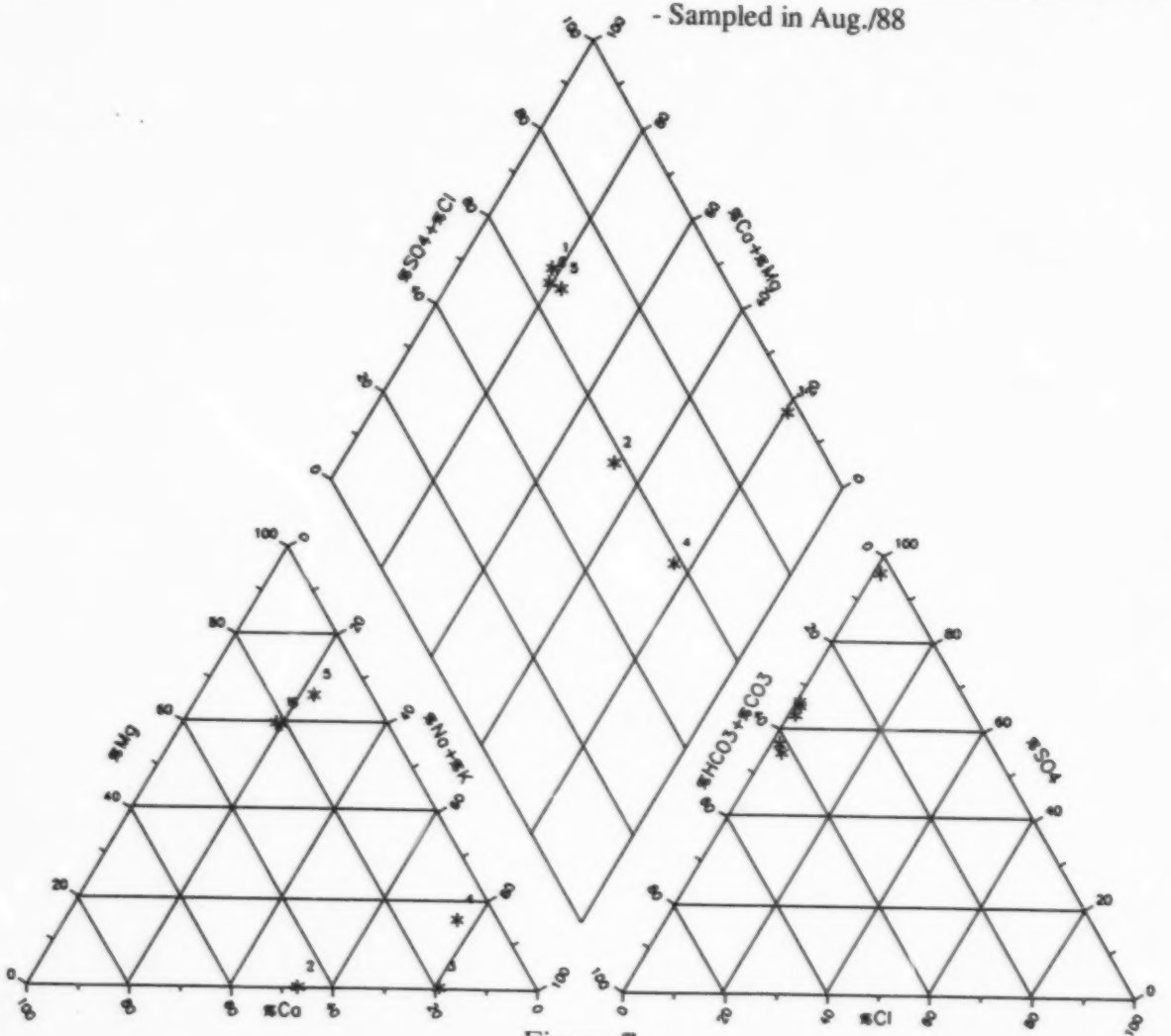


Figure 7

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE WATER CHEMISTRY
- Location: Nest 5 - overburden piezometers as numbered
- Sampled in Aug./88

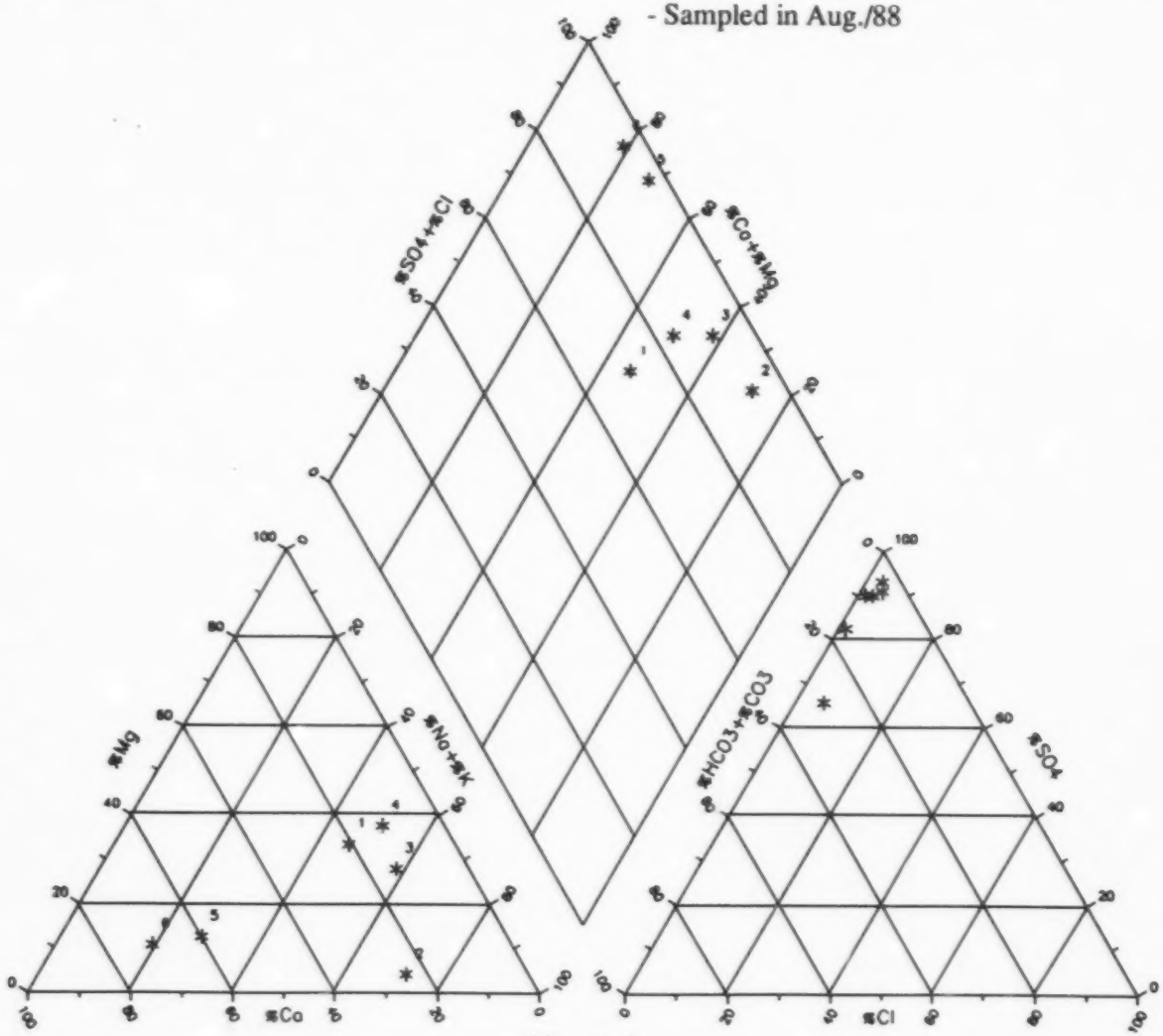


Figure 8

PIPER DIAGRAM
MAJOR ION CHEMISTRY

NANTICOKE AREA SURFACE WATER CHEMISTRY
- Background data obtained by Golder Associates
- Surface water samples are from Hickory Creek

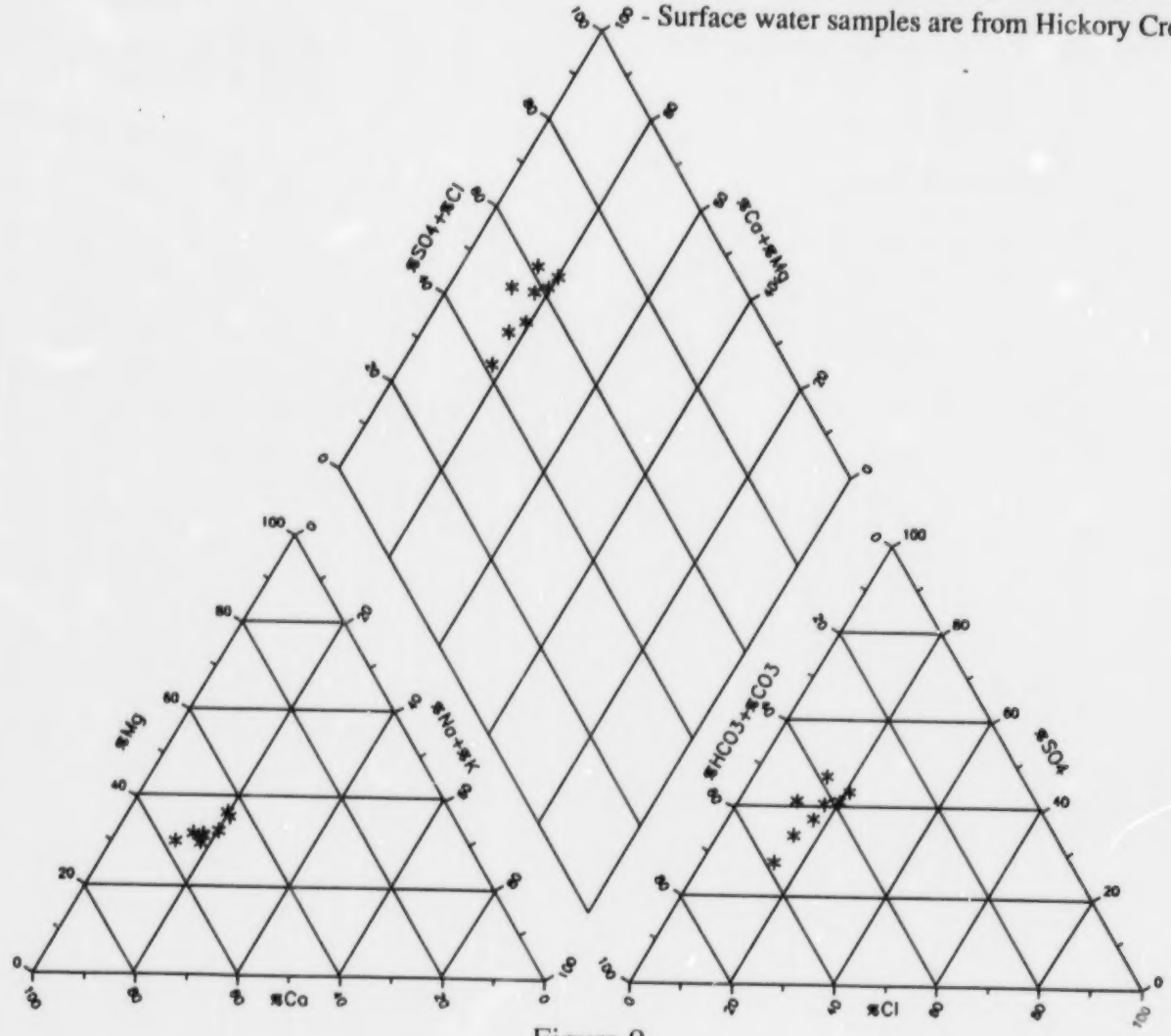


Figure 9

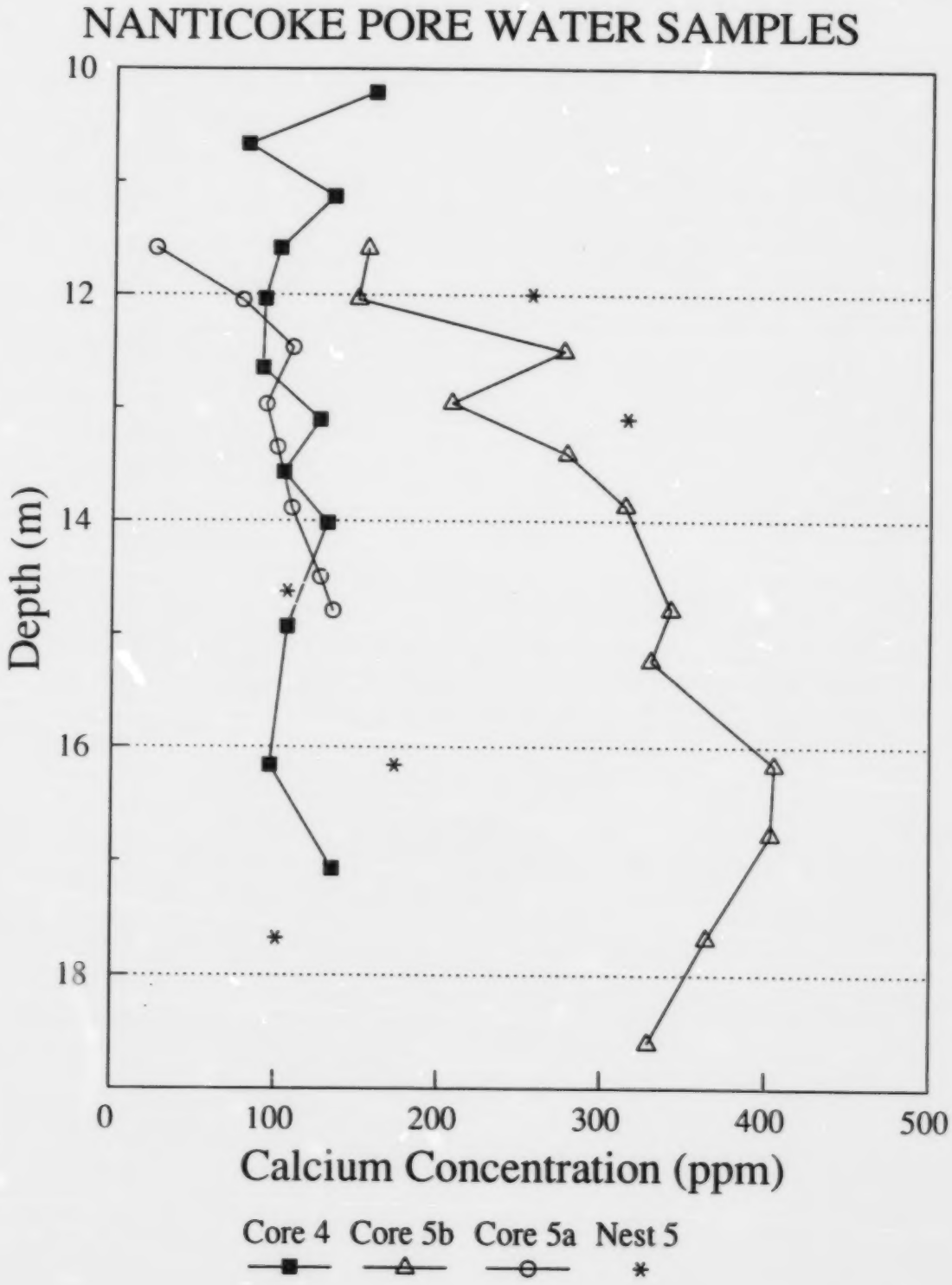

NANTICOKE PORE WATER SAMPLES
10
12
14
16
18
Depth (m)
0
100
200
300
400
500
Calcium Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 10

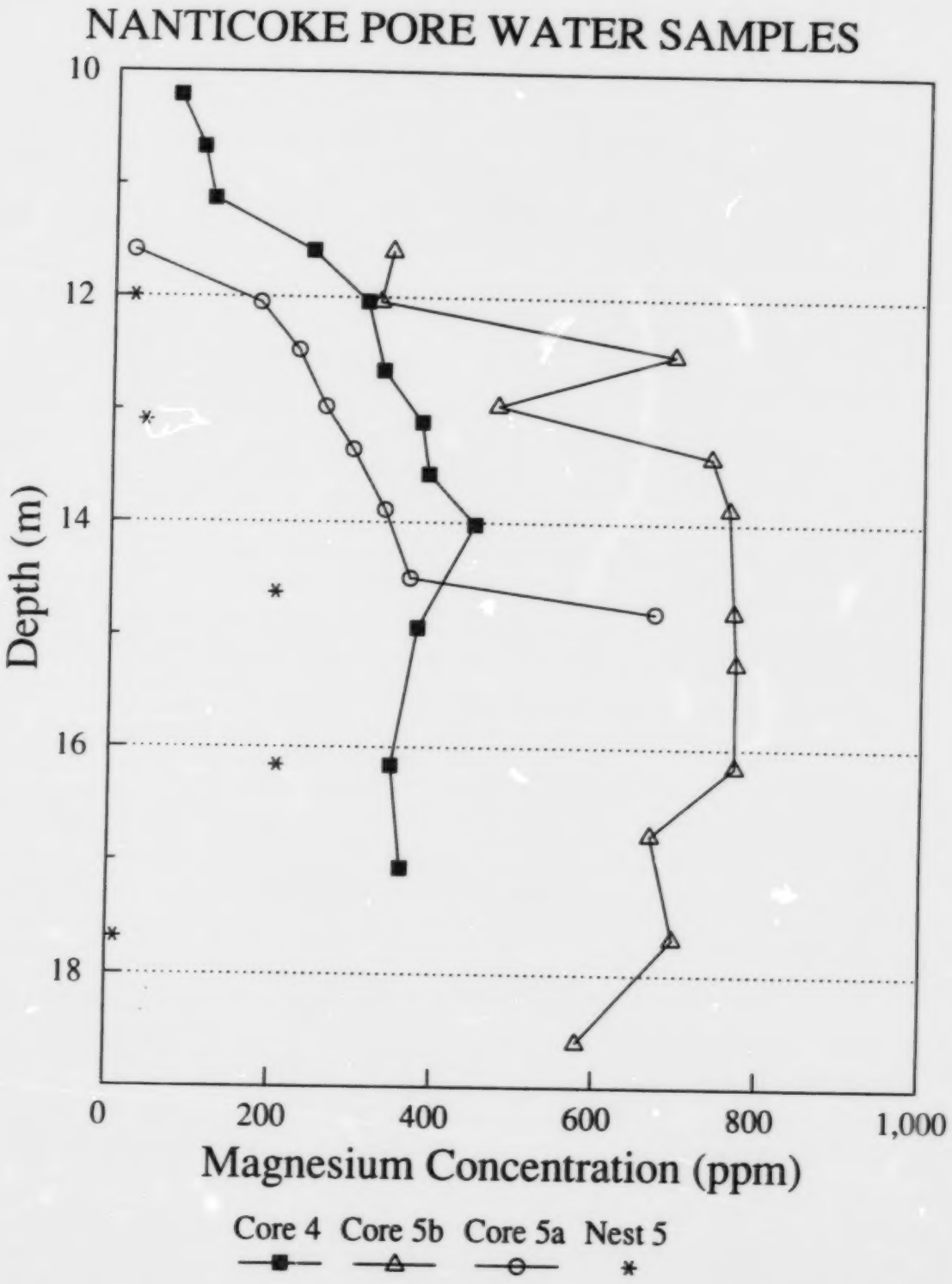

NANTICOKE PORE WATER SAMPLES
10
12
14
16
18
Depth (m)
0
200
400
600
800
1,000
Magnesium Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 11

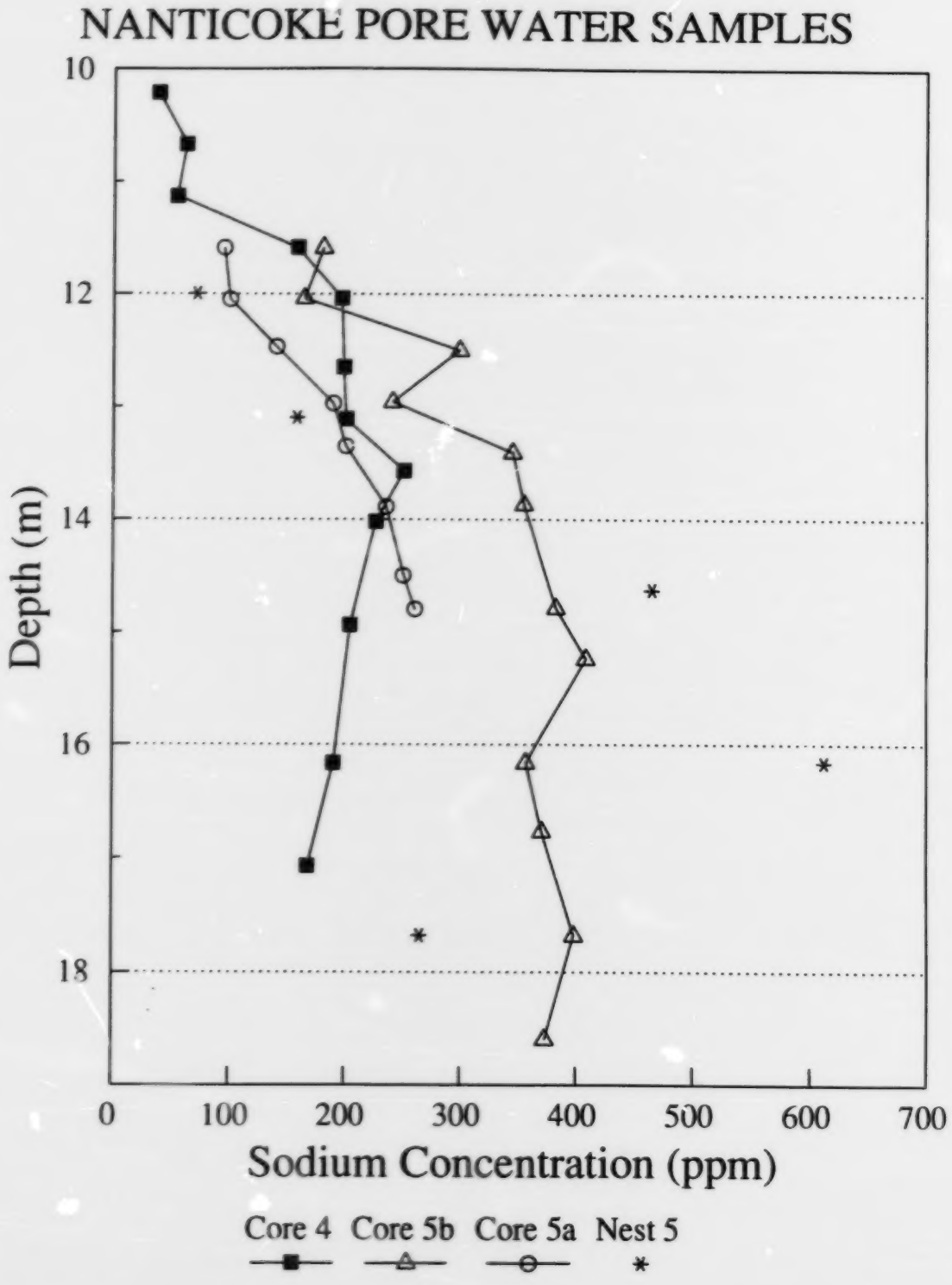

NANTICOKE PORE WATER SAMPLES
10
12
14
16
18
Depth (m)
0
100
200
300
400
500
600
700
Sodium Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 12

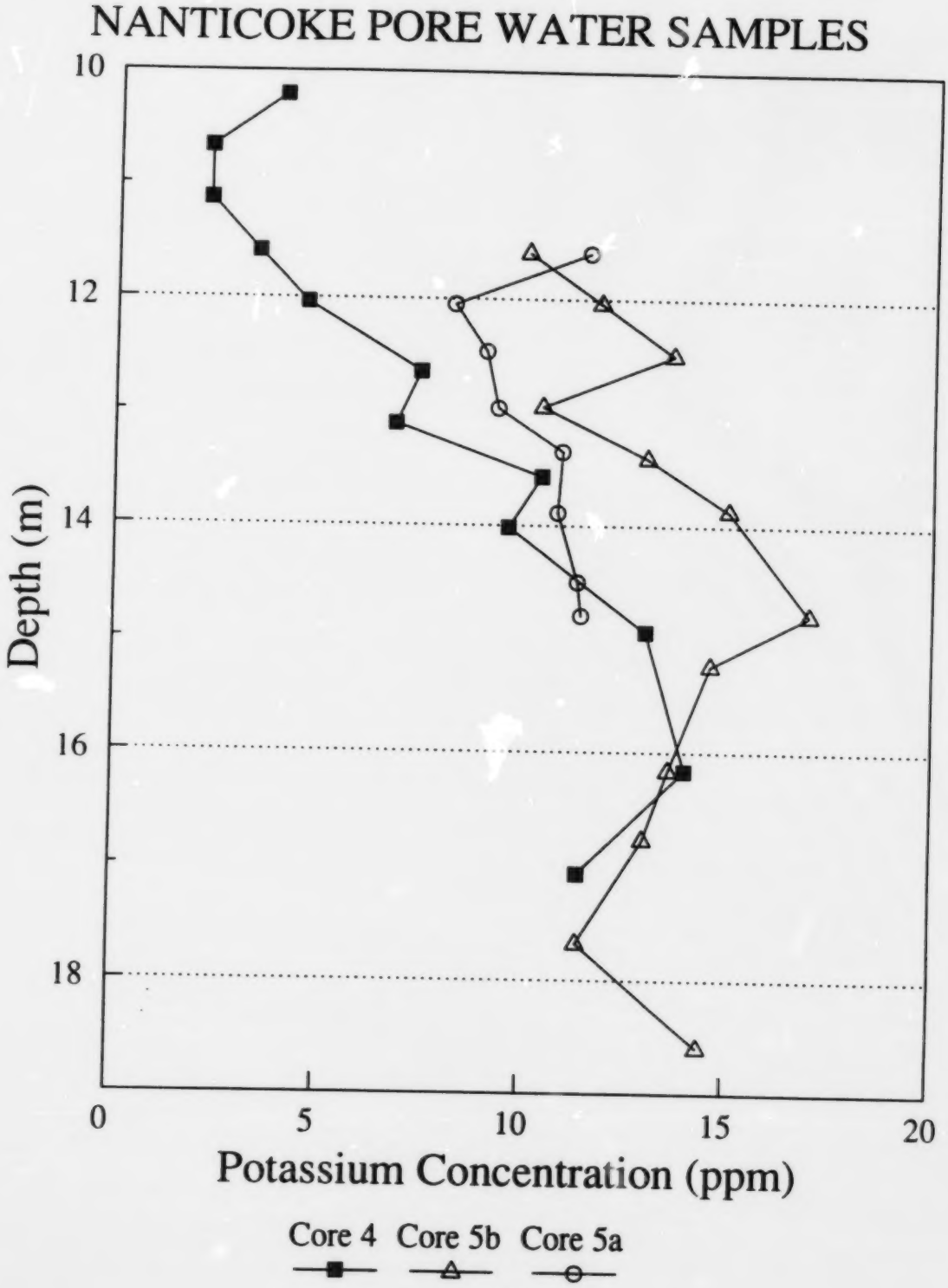

NANTICOKE PORE WATER SAMPLES
10
12
14
16
18
Depth (m)
0
5
10
15
20
Potassium Concentration (ppm)
Core 4
Core 5b
Core 5a

Figure 13

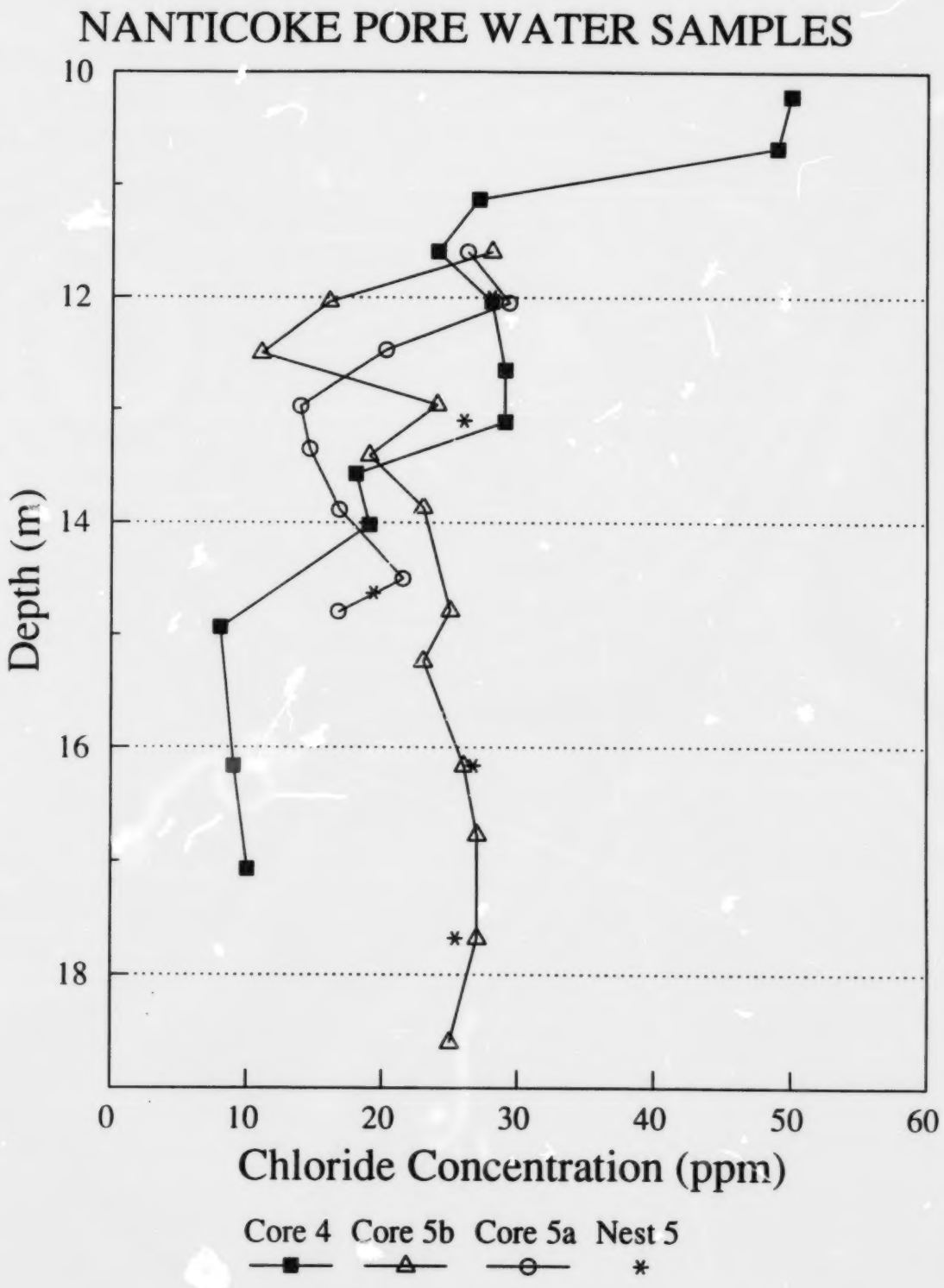

NANTICOKE PORE WATER SAMPLES
Depth (m)
10
12
14
16
18
0
10
20
30
40
50
60
Chloride Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 14

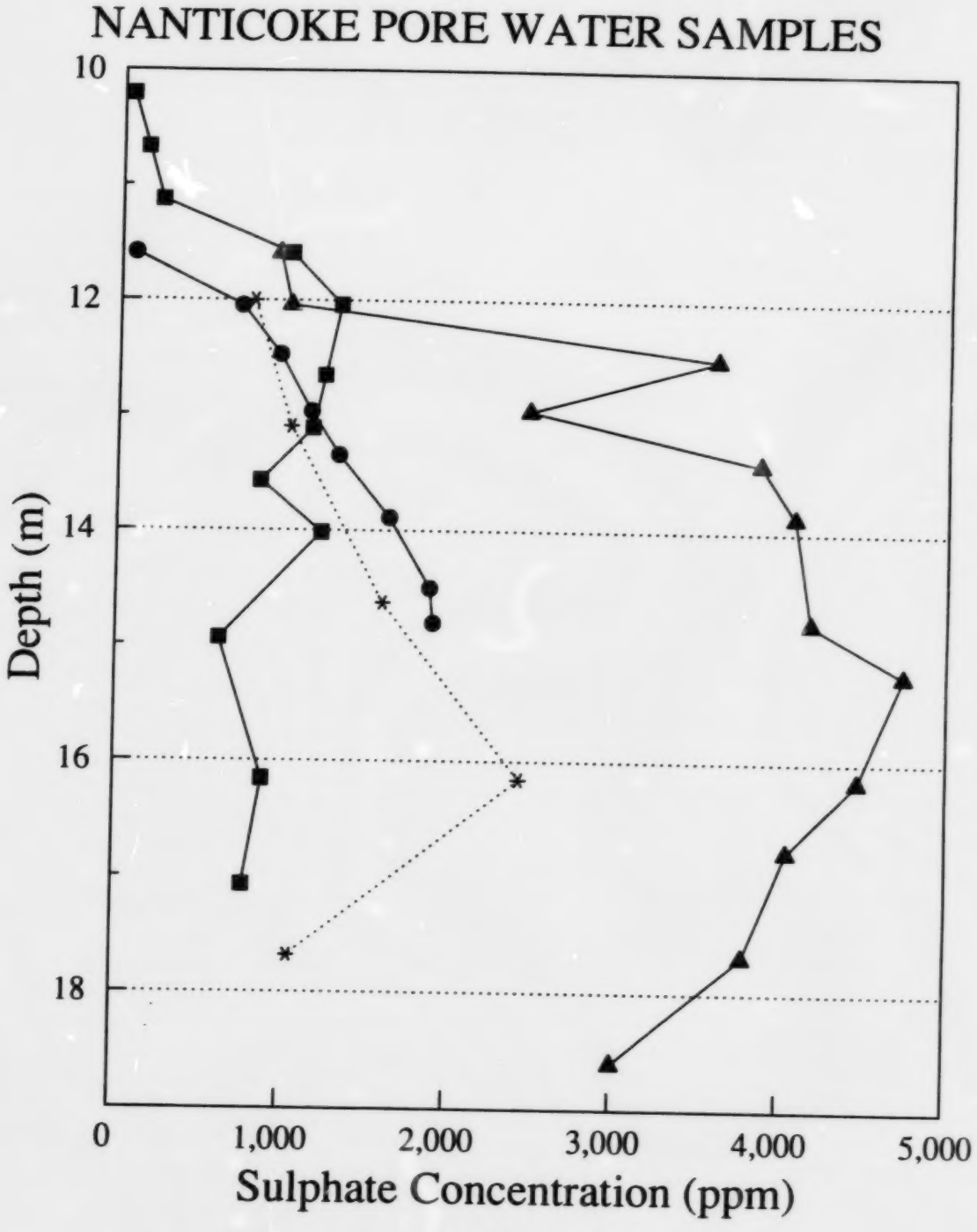

NANTICOKE PORE WATER SAMPLES
10
12
14
16
18
Depth (m)
0
1,000
2,000
3,000
4,000
5,000
Sulphate Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 15

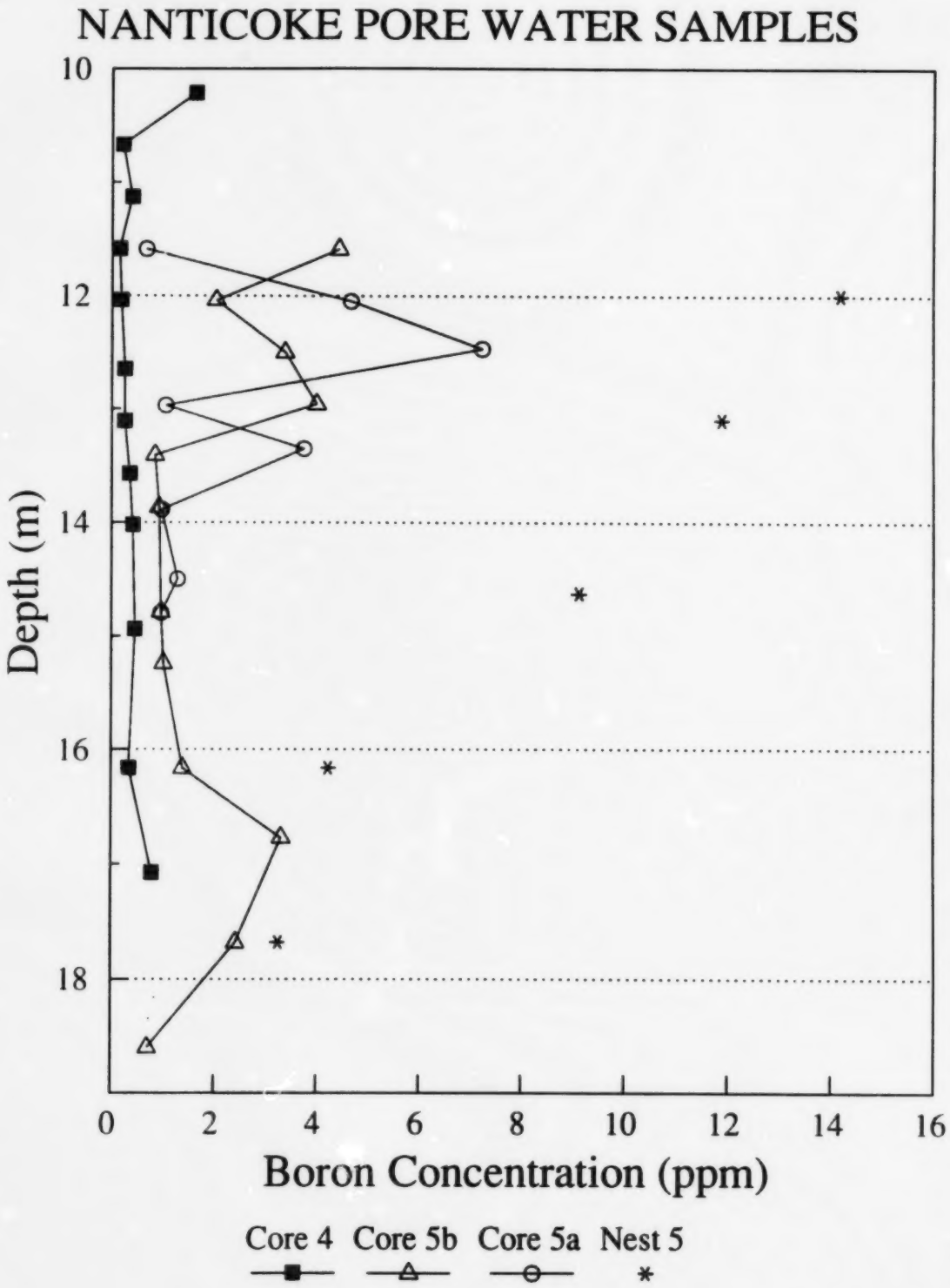

NANTICOKE PORE WATER SAMPLES
Depth (m)
10
12
14
16
18
0
2
4
6
8
10
12
14
16
Boron Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 16

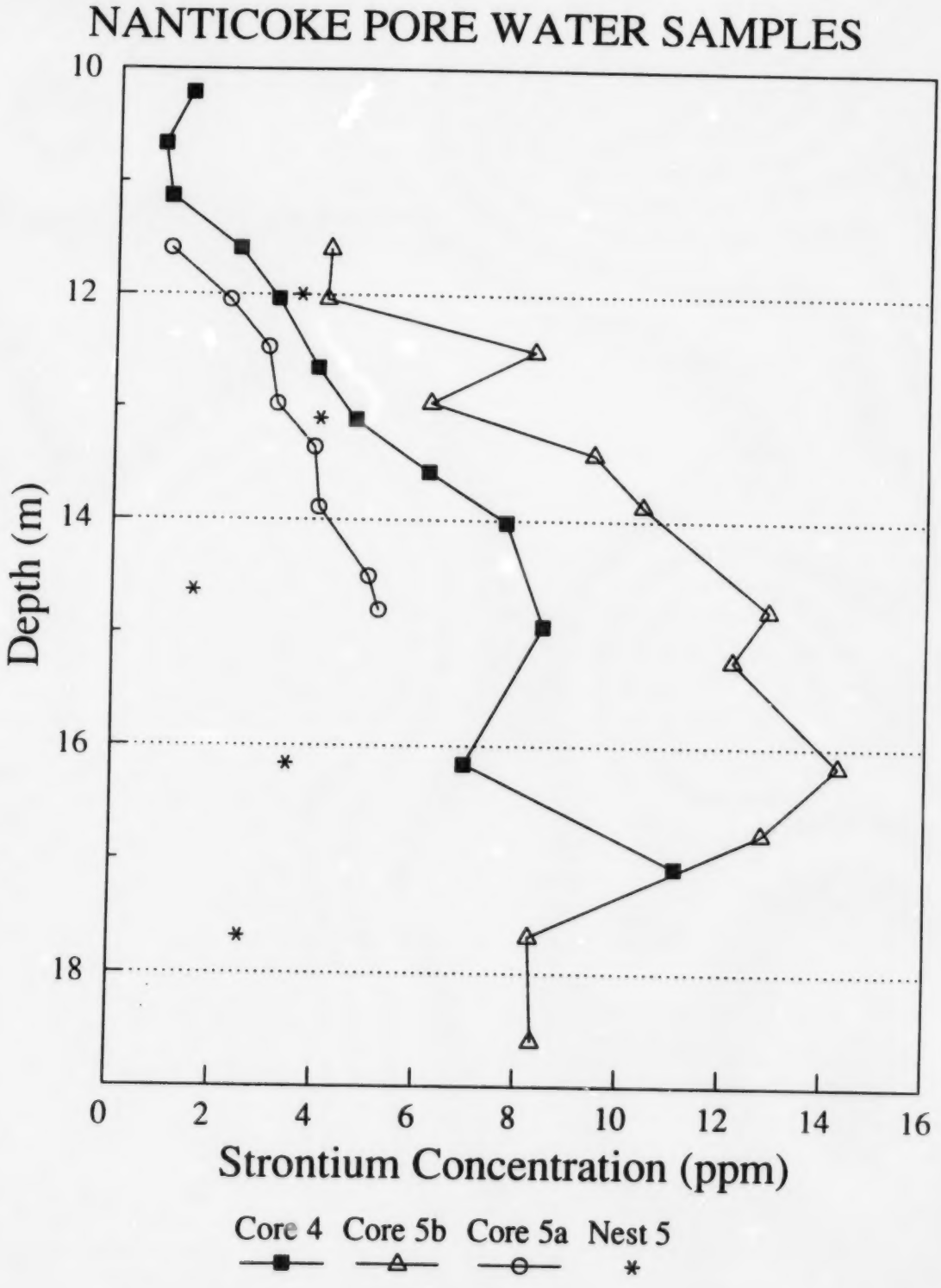

NANTICOKE PORE WATER SAMPLES
Depth (m)
10
12
14
16
18
0
2
4
6
8
10
12
14
16
Strontium Concentration (ppm)
Core 4
Core 5b
Core 5a
Nest 5

Figure 17

PIPER DIAGRAM
MAJOR CATION CHEMISTRY

NANTICOKE PORE WATER CHEMISTRY
- Core 4 (10.0-17.0 m BGL) obtained near Nest4 in Oct./88
- Samples are numbered sequentially with depth

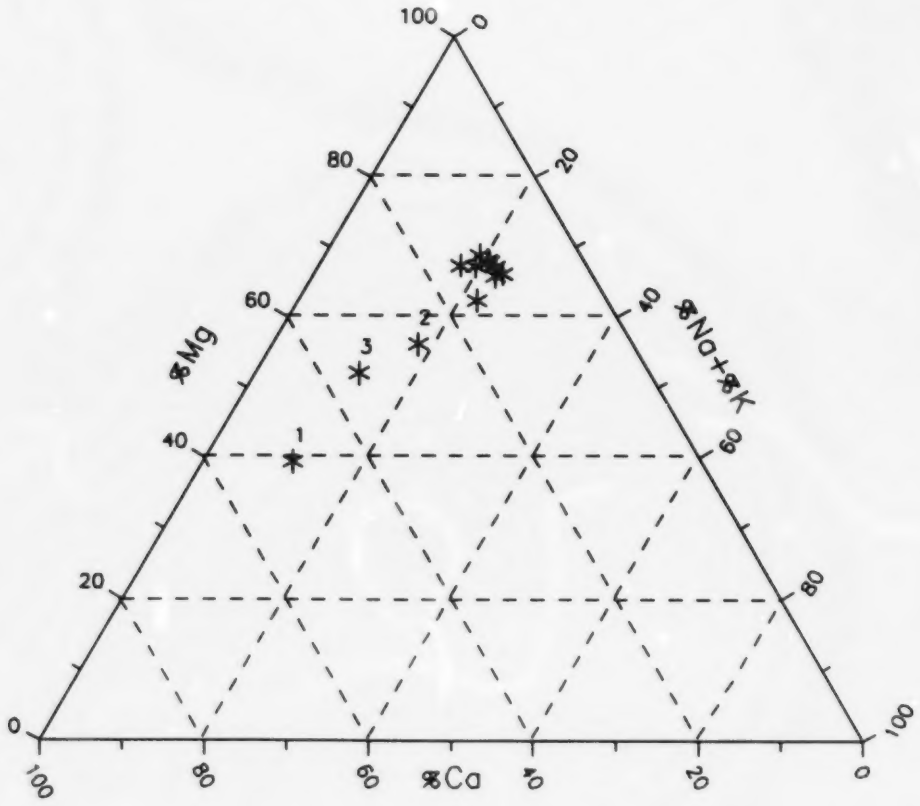


Figure 18

PIPER DIAGRAM
MAJOR CATION CHEMISTRY

NANTICOKE PORE WATER CHEMISTRY
- Core 5a (11.5-16.0 m BGL) obtained near Nest 5 in Sept./87
- Samples are numbered sequentially with depth.

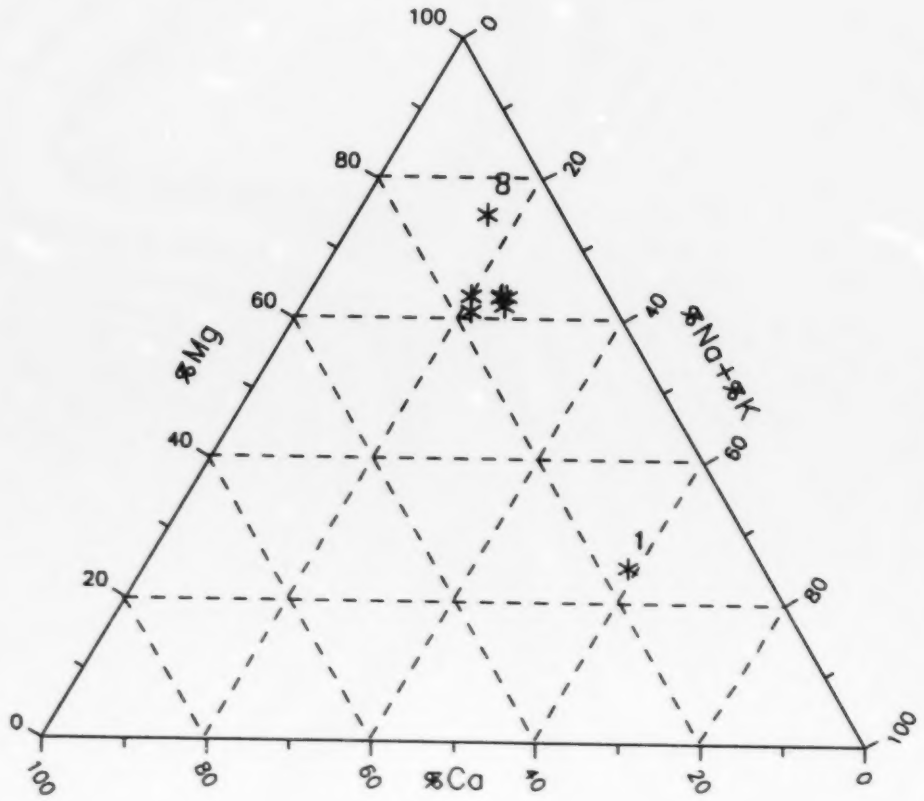


Figure 19

PIPER DIAGRAM
MAJOR CATION CHEMISTRY

NANTICOKE PORE WATER CHEMISTRY
- Core 5b (10.5-18.4 m BGL) obtained near Nest 5 in Oct./88

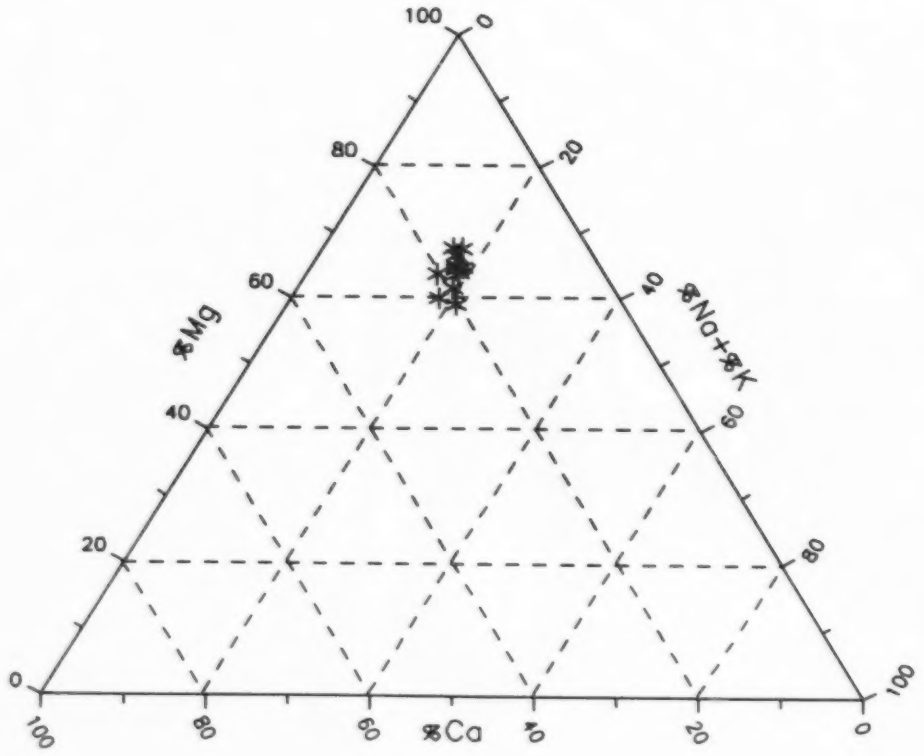


Figure 20